Framework for a Unified Monitoring, Assessment and Reporting Program (UMARP) for the Bay-Delta
2010 Report

<u>Committee Chair</u>:
Samuel Luoma

<u>Committee</u>:
Roger Fujii
Bruce Herbold
Mike Johnson
Wim Kimmerer
Anke Mueller-Solger
Pete Smith
Darcy Austin

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Prologue

Development of a convincing set of “performance measures” is an essential part of an “adaptive management” approach to applying science to water policies in the San Francisco Bay-Delta. Studies of the state of the estuary (Estuary Project, 2011) or the State of the Bay (Bay Institute; SFEI) include ecosystem “indicators”, but these are either limited in scope and/or have had limited impact on discussions of policy. Identification and implementation of performance measures that impact the policy dialogue remains an elusive goal.

The conventional literature suggests that a small set of simple performance measures for an ecosystem is the easiest to understand. Most papers on indicators or performance measures accept that concept. But, effectively interpreting a constrained set of indicators is hindered by the complexity of ecosystems. Applying a small set of indicators to policy is hindered by the constantly changing nature and specificity of policy questions. Luoma et al (2011, Report to Bay-Delta Stewardship Council’s Science Program) report here on a framework for a unified environmental monitoring, assessment and reporting program (UMARP) for the San Francisco Bay-Delta estuary and its watershed, that addresses both of these issues. The UMARP report provides a methodology for identifying ecosystem indicators. It identifies some specific, carefully defined choices of metrics that will characterize policy-relevant changes in the system. It also describes an approach for implementing effective assessment and reporting on the links between these measures of ecosystem performance, and implications of environmental change. This broad base of indicators, metrics and measurements is intended to be the platform from which smaller suites of (less than 20) indicators can be chosen to address and track implications of any specific policy at any time (each policy question has its own small set of indicators). UMARP is thus proposed as a means of addressing both ecosystem complexity and the need for flexibility and simplicity in applying that data to policy performance. The core choices for indicators suggested in this draft report provide the beginning of the base from which key measures can be relatively easily selected for objectively tracking performance of a policy question (e.g. how will the Bay-Delta environment change in response to construction of an “isolated facility”?). The methodology described herein provides the rules for making those choices. The four grand challenges identified by the committee frame the policy arena at which UMARP can be directed.

The committee recognizes that there is significant work left to do in completing the UMARP plan. But there is enough substance completed to open this plan to the broader community. It is an opportune time for peer review and constructive discussion of the approach, alternatives and/or modifications, as well as the priorities for next steps.

Samuel N Luoma, Nov. 4, 2011

Introduction

The purpose of this report is to provide a framework for a unified environmental monitoring, assessment and reporting program (UMARP) for the San Francisco Bay-Delta estuary and its watershed.

Environmental monitoring provides important scientific information that helps policy makers, managers, and the public address challenging environmental issues. In the San Francisco Bay-Delta estuary and its watershed (collectively, the Bay-Delta), environmental monitoring has long played an important role and many long-term monitoring programs exist. Additional programs may soon be added as a new Bay Delta Conservation Plan (BDCP, currently under development) gets under way. Monitoring, along with appropriate and timely assessment and reporting, will undoubtedly also be a key element of the new science-based and adaptive management strategies laid out in a newly mandated long-term Delta Plan to be completed by January 1, 2012.

The ingredients are in place to pull together a common monitoring and assessment framework for the Bay-Delta. The many challenges to the system are well known and urgent. Many valuable monitoring programs exist. The importance of coordination among focused programs and the need to interpret and contextualize data are recognized. Especially in recent years, a more systemic management desire has identified many important data gaps. A drive is underway to establish performance measures for the system, and conceptual models now exist for many key subject areas. A unifying monitoring framework is required to provide a common focus and structure for aspects of each of these ingredients. A common framework provides the links needed to expand the effectiveness of the unique and constructive partnership of science and policy already in existence.

We propose such a framework and outline a strategy for its development and implementation, along with examples of key monitoring components. The common focus is provided by four overarching *Grand Challenges* for environmental policy and management in the Bay-Delta. A common structure is provided by a unifying program design which links the Grand Challenges with a suite of carefully selected *Important Environmental Attributes (IEAs)* and by requirements for coordination, data management, assessment and reporting. IEAs are selected with the help of *conceptual models* about ecological responses to drivers and stressors associated with the *Grand Challenges.* IEA monitoring and assessment is based on a system of *targets, indicators, metrics,* and *measurements.*

Why a Monitoring Framework?

A framework is **"**The underlying structure; or a structure supporting or containing something." "Structure" refers to the particular arrangement of the components of a system – its elements, interconnections, and function/purpose. The UMARP framework is intended to provide a ***common structure*** that supports and unifies monitoring across relevant spatial and temporal scales, ecological processes, and diverse habitats and biota common to complex ecosystems. It also brings a ***common focus*** to monitoring programs and monitoring plans already in place and under development in the Bay-Delta. The value of monitoring under the framework will be judged by how well it improves ecological understanding and provides useful information for water and environmental policy and management decisions.

Essential to ensuring the relevance of any monitoring framework to policy is an understanding of the scientific information needed to make sound policy and management decisions now and into the future. UMARP revolves around information needs to address four overarching G*rand Challenges* for environmental policy and management in the Bay-Delta:

1. **To understand how the ecosystem is changing in response to changes in infrastructure and water management actions that affect water supply reliability;**
2. **To understand how the ecosystem is changing in response to ecosystem restoration activities and to changes in regulations and rulings to protect the environment;**
3. **To understand how the ecosystem is changing in response to exogenous processes (climate change, sea level rise, ocean processes);**
4. **To understand how the ecosystem is changing in response to external changes in human activities like population growth, changes in land use, changes in agricultural runoff, and inadvertent importation of exotic species.**

The water and environmental challenges faced by California are strongly influenced by what happens in the San Francisco Bay-Delta and its watershed. Every analysis of the existing situation suggests that management of California's water, and with it the role science and monitoring, will change. The 2008 Delta Vision Report and Strategic Plan emphasized the importance of giving equal priority to water supply reliability and the ecological status of the Delta. This was written into law as the "coequal goals" of "providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem" in the comprehensive water bill package enacted by the California Legislature and Governor Schwarzenegger in late 2009. This bill package contained the Sacramento-San Joaquin Delta Reform Act of 2009 (Act) which requires the completion of a comprehensive, long-term management plan for the Delta (the Delta Plan) by the newly created Delta Stewardship Council (Council) by January 1, 2012. The Act also specifies that the more narrowly focused Bay-Delta Conservation Plan (BDCP), under development by State and Federal agencies and others, has to be "consistent" with the Delta Plan.

The main purpose of the Delta Plan is to meet the coequal goals as well as a number of more specific objectives about water management, ecosystem restoration, water quality protection, protection of the Delta as a unique, evolving place, and protection from catastrophic floods. By law, science – including monitoring - is intended to play an important role in the development and implementation of the Delta Plan. The Delta Plan is supposed to "be based on the best available scientific information;“ “include quantified or otherwise measurable targets associated with achieving the objectives of the Delta Plan;” utilize monitoring, data collection, and analysis of actions sufficient to determine progress toward meeting the quantified targets;” “describe the methods by which the Council shall measure progress toward achieving the coequal goals;” “where appropriate, recommend integration of scientific and monitoring results into ongoing Delta water management;” and include a “science-based, transparent, and formal adaptive management strategy for ongoing ecosystem restoration and water management decisions."

Clearly, monitoring will be a key component of the science-based, adaptive management strategies needed to meet the goals and objectives of the Delta Plan and other plans such as the BDCP and the overarching grand challenges. Uncertainties will continue to plague our knowledge of the risks and benefits of every policy choice laid out in these plans. Coordinated, comprehensive monitoring and assessment allows California a hedge against uncertainties. Environmental management in the face of uncertainty requires flexibility. But it also requires ongoing environmental monitoring and assessments that allow managers to understand environmental changes. This is especially important for changes that might signal policy successes or provide early warnings about tactics or strategies that need refinement.

UMARP Goals and the UMARP Framework

From the above, the ultimate goals of UMARP monitoring derive from why monitoring data, interpretation and reporting are needed:

1. detect and quantify important environmental changes and trends, as defined around the Grand Challenges;
2. contribute toward interpreting changes and trends and their causes;
3. contribute toward anticipating future changes;
4. check the validity of models, both quantitative and conceptual, and understand and define important ecological relationships;
5. support planning and day to day management of water infrastructure and ecosystem restoration projects

The framework is the first step in establishing a UMARP. The first goal of the framework is to define a structure for monitoring, assessment and regular reporting of data and information that track environmental changes as they occur in the Bay-Delta and its watershed. Within that structure, interpretation of monitoring, assessment and reporting out to policy makers, managers, managers, and the public have equal priority with data collection. Secondly, the framework will identify important attributes of the Bay-Delta ecosystem and develop ecologically and socially justifiable targets and performance measures that can be employed to systematically track changes in these attributes in response to the Grand Challenges. Thirdly, the framework sets out examples of key monitoring data to fill in the performance measures; data that should be tracked, interpreted and reported through time. The ultimate purpose is to frame a monitoring environment that is sufficiently comprehensive to detect major surprises early in their development and sufficiently flexible to serve California's diverse and evolving water management needs. Providing a common structure and identifying a unified set of data, of value to all institutions, will help institutions set priorities in their programs and identify links to other monitoring efforts. Once the unified core of data needs is established it will be in the interest of all programs to sustain that core.

Once the framework is adopted, care should be taken with adjusting the overall structure because it defines fundamental elements, interrelationships, and functions that are essential to the ultimate success of a UMARP. In contrast, monitoring data may be adjusted and/or supplemented with time and experience. In addition, more detailed study or monitoring can delve more deeply into any aspect supported by the core structure.

Fundamental Elements of the Monitoring Framework

The framework defines the ingredients of the unified program. The purpose is to detect, track, interpret and anticipate change in important environmental attributes of the Bay-Delta system. The ingredients include existing monitoring programs; management targets and performance measures to guide what aspects of those programs are incorporated into UMARP; a plan for interpretation and reporting; a data management plan; and a strategic plan for implementation.

The Framework defines *six fundamental elements* of the UMARP:

1. **Identification of targets and the indicators, metrics and measurements that make measures of performance for important environmental attributes.**
2. **Coordination of data from existing monitoring programs.**
3. **Ongoing evaluation and interpretation (assessment) of monitoring data**
4. **Regular reporting of results**
5. **Appropriate data management across coordinated programs**
6. **Building a sense of common purpose**

Unified Program Design: Targets and Performance Measures

Successful environmental policy requires clear goals and objectives. These should be translated into measurable management targets and performance measures. Good targets are *SMART*: *S* – specific, *M* – measurable , *A* – achievable, *R* – relevant, and *T* – time-specific (Citation). Performance measures use monitoring data to track success or failure on the way to reaching a management target. They directly connect policy and management. The establishment of performance measures is now often required in environmental planning processes. For example, the Delta Plan has to include "*quantified or otherwise measurable targets associated with achieving the objectives of the Delta Plan*" and "*performance measurements that will enable the Council to track progress in meeting the objectives of the Delta Plan. The performance measurements shall include,* *but need not be limited to, quantitative or otherwise measurable assessments of the status and trends in all of the following: (a) The health of the Delta's estuary and wetland ecosystem for supporting viable populations of aquatic and terrestrial species, habitats, and processes, including viable populations of Delta fisheries and other aquatic organisms; (b) The reliability of California water supply imported from the Sacramento River or the San Joaquin River watershed.*"

Targets and performance measures also require a strategy for collecting data. The UMARP strategy is based on a careful choice of *important environmental attributes (IEAs*), *targets* that set the desirable condition of IEAs, and *indicators, metrics,* and *measurements* that define the status and trends for the IEA (Fig. 1). Clear terms are an essential first step in defining the strategy. For UMARP, *IEAs* include broad ecosystem components or processes (e.g. populations of species of concern like salmon or delta smelt, water quality, flow regime) that are central to the concerns of the public and resource agencies. IEAs respond to various drivers including external drivers (e.g. climate), management actions (e.g. habitat restoration, flow regulation), and stressors (e.g. pollution). The IEAs chosen as most important for UMARP are directly relevant to the Grand Challenges. They are based on *conceptual models* about ecological responses to the drivers and stressors associated with the Grand Challenges. *Targets* provide a benchmark against which to evaluate IEA condition and the success or failure of management actions. They are also essential for developing environmental report cards. Targets have not been identified for all Bay-Delta IEAs but they can be set for all measures of IEA condition and used for regulatory purposes. *Indicators* represent important responses of IEAs to drivers. They are used for assessment and communication of trends in environmental variables and metrics. They provide insight into the condition of IEAs that is suitable for interpretation and application by policy-makers. Indicators are useful to track the performance of management actions (i.e. can be used as performance measures). Some indicators are based on one measured variable, while others integrate and condense information from several independently measured variables. Examples of indicators include juvenile salmon production, water temperature, environmental flows, extent and duration of flood plain inundation. *Metrics* are used to quantitatively describe the status for an indicator of IEA condition. They can be single data points, but are more often composite measures of relevant data and are calculated or estimated from one or more measurements (e.g. calculated abundance of adult salmon in a given stream for a year, average monthly dissolved oxygen concentration at a monitoring station). *Measurements* are the actual measurements made in the field or laboratory that form the basis for the metric.

For example, for the IEA *salmonid populations*, one indicator might be "environmental water flow", and a metric might be average monthly San Joaquin River discharge, as calculated from measurements of instantaneous San Joaquin River discharge at Vernalis (see later discussion). For the IEA *longfin smelt populations*, a key indicator would be X2. One metric might be daily or monthly mean salinity at each of a series of continuous monitoring stations, and one of the component variables would be measurements of conductivity at 15-minute intervals at Port Chicago.

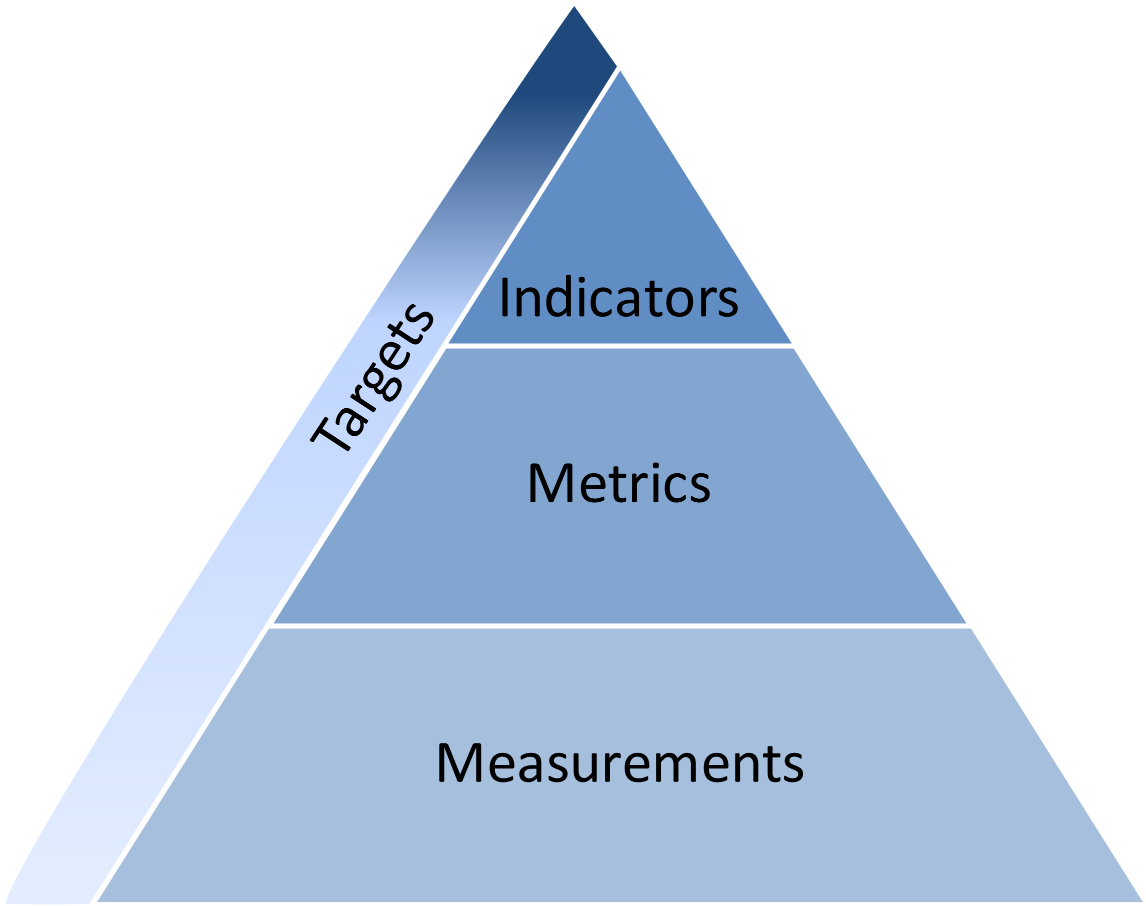

Figure 1. Hierarchy of Indicators, Metrics and Measurements for Important Environmental Attributes (IEAs). Targets can be set for each IEA measure.

A given measure can be an indicator in one context, a metric in another or a measurement in a third depending upon how the measure is used. In some cases these definitions overlap: for example, 15-minute conductivity at Rock Slough might be the measurement used to develop a metric such as daily maximum salinity at Rock Slough, which would also be an indicator for an IEA “drinking water quality.”

The UMARP framework is not constrained geographically. The spatial extent is expected to vary as necessary to address each Grand Challenge and to assess the potential causes of change in each IEA. The geographic range of UMARP as a whole, then, is what is necessary to address the Grand Challenges and understand the IEAs.

A chain of reasoning will explain the relevance of indicators, metrics and measurements to each IEA and how they all relate to one or more grand challenges. The chain of reasoning must explain why each indicator is important to understanding the status of the IEA; how each metric tracks the indicator; and finally how measurements are transformed into metrics. The IEAs and their indicators thus provide a mechanism to monitor and integrate key *structural elements of the ecosystem* (habitats, geomorphology) and *key processes* (stressors, limiting factors, biogeochemical cycles, hydrology) to understand why changes are occurring and as a basis for evaluating implications of policy changes (such as infrastructure changes; Dennison et al, 2007).

Existing Monitoring Programs: Coordination of data

UMARP does not entail replacement or even, in most cases, modification of existing monitoring programs; nor is meant to create a new monitoring program. Rather, it will require coordination and integration of aspects of existing programs, together with initiation of any new monitoring that appears necessary to address the Grand Challenges. It provides a unifying context from which to evaluate monitoring data collected for other purposes. The UMARP Framework provides the structure and purpose for assembling the selected data from existing monitoring programs.

Many programs exist, for various purposes, to monitor aspects of the San Francisco Estuary and its watershed (e.g. SFEI, 2007). These include the monitoring of the Interagency Ecological Program and the Regional Monitoring Program for San Francisco Bay. There are also water quality monitoring programs in the Delta, the San Joaquin River and the Sacramento River watersheds. Existing monitoring programs were not specifically designed to address Grand Challenges, but have their own legitimate purposes. The purpose of these programs include: **compliance monitoring** to determine whether regulatory or management targets (variously also known as standards, criteria, or objectives) are being met; **operations support monitoring** intended to assist in making water management decisions such as the timing and extent of export pumping; **baseline monitoring** intended to track the status and trends of various environmental attributes of interest and assist in interpreting and refining other monitoring results; and *ad hoc* monitoring (durations of months to many years done by institutions like USGS and universities) that is needed to understand or define important physical and ecological relationships, learn about the ecosystem, or to collect data to support models. Many of the latter collect data on specific issues or specific locations (e.g. UC Davis' fish monitoring in Suisun Bay; USGS' water quality monitoring; other examples listed in SFEI, 2007). These research projects have produced data of great relevance to interpreting environmental change in the system, but they are defined as *ad hoc* because there is no institutional commitment to the continuity of into the future

Over the years, many attempts have been made to assess and organize monitoring needs and activities. The Comprehensive Monitoring and Research Program (CMARP), for example, was a group of plans, each of which described monitoring needs for a different aspect of the Bay-Delta system. The Terrestrial and Amphibian Monitoring Plan (TAMP) provided a comprehensive view of what could be monitored in riparian environments. CALFED's Ecosystem Restoration Program (ERP) has a strategic plan that lists 12 major uncertainties with regard to restoration, along with 12 goals, 32 objectives, 200 targets and even more potential actions that could guide development of performance measures and associated monitoring and assessment (Detweiler memo, 2006). Projects have also been funded to develop needs for wetlands monitoring; and wetlands monitoring plans exist for the Bay. Largely because of their large scope, and therefore high costs, these plans have not been broadly adopted.

Integration of existing monitoring efforts is improving. The San Francisco Estuary Institute (SFEI) and the U.S. EPA Region 9, in collaboration with others, initiated an effort to improve water quality monitoring and assessment in the San Joaquin River Region. Similar efforts exist in the Sacramento River watershed. The Central Valley Regional Water Quality Control Board has begun coordinating water quality monitoring, including the Delta. The California Water Quality Monitoring Council (WQMC) was established in 2007 to "develop specific recommendations to improve the coordination and cost-effectiveness of water quality and ecosystem monitoring and assessment, enhance the integration of monitoring data across departments and agencies, and increase public accessibility to monitoring data and assessment information." Its Wetland Monitoring Workgroup recently (April 2010) released a report laying out "Tenets of a State Wetland and Riparian Monitoring Program (WRAMP)." Even more recently, the WQMC established California Estuary Monitoring Workgroup. The initial focus of this workgroup is on the Bay-Delta and it may come to play an important role in assessment and reporting of monitoring data.

Coordination across these efforts, however, has not been an emphasis. Experience elsewhere suggests integration of monitoring efforts and data is most likely to succeed if a common framework can be identified, creating an environment where the distributed programs find common ownership in addressing a common goal(s). The goal of coordination is to use the minimum amount of data collection to provide the maximum amount of information. Coordination is an important aspect of UMARP and will be driven by the data needed for each indicator and the existing sources of the data. Coordination can also build a sense of common purpose among the distributed programs and a sense of common ownership of the monitoring core data across the Bay-Delta community (including the watersheds). To achieve this, communication with the existing programs must be conducted in a participative, not a consultative atmosphere, (i.e. participatory workshops and interactive websites instead of consultative lectures). Discussions should be focused on IEAs and their associated targets and measures instead of geography, agencies, or single problems.

Interpretation

Interpretation is a critical element of UMARP - UMARP makes assessment an expectation. This requires a clear statement of the questions that need to be addressed. Importantly, questions should not require overly complex answers and should be limited to a manageable number. The new CA WQMC's "My Water Quality" web portal (http://www.waterboards.ca.gov/mywaterquality/) relies on such a question-driven approach to interpret water quality and other environmental monitoring data collected throughout California. In UMARP, interpretation of monitoring will focus on questions central to the Grand Challenges and on the condition of the IEAs relative to the condition in previous years or to any targets that may exist. The intent is to create an ongoing program of assessment that is scientifically robust and interdisciplinary within each

Grand Challenge and across the Grand Challenges. More specific questions will build from the Grand Challenges and those questions are likely to change through time. A long-term perspective is also a critical ingredient in interpretation. UMARP sets the expectation that interpretation will be conducted (and reported) regularly (e.g. every year). Therefore, a successful program of interpretation will require dedicated resources (people, time and money) as part of the initial plan and initial budget. In UMARP, interpretation is as important and as resource-intensive as the monitoring itself.

Progress has also been made in integrating monitoring and research activities to answer questions relevant to policy makers in a more timely manner. For example, over the past five years, the Interagency Ecological Program has conducted a multi-disciplinary, multi-institutional investigation of the causes of a sudden decline in the abundance of four pelagic fish species in the Delta that has become known as the "Pelagic Organism Decline" (POD). The simultaneous step decline in these four species was detected in long-term fish monitoring data collected by the IEP. The ensuing investigation made use of many types of monitoring data along with broad suites of studies and integrative analysis and synthesis efforts conducted in partnership with National Center for Environmental Assessment and Synthesis (NCEAS) program at UC Santa Barbara. In addition, this effort was characterized by a greater emphasis on reporting of results ranging from peer reviewed scientific publications to presentations to the public and policy makers. Such assessments provide a formal mechanism for coordination and cooperation among investigators and a formal assignment to feed back advice to managers and decision makers and are a good model for UMARP. But unfortunately, they are not yet a routine part of many monitoring programs. A common monitoring framework should facilitate ongoing interpretation and reporting of this sort.

Reporting

Developing the details of how to regularly report the findings of UMARP to scientists, policy makers and the publc is an important aspect of the strategic plan for implementation. Reporting out to the public and passing comprehensible information useful to managers will have priority equal to that of data collection and technical interpretation. Clear targets and performance measures provide a basis for reporting on the status of the Bay-Delta, its watershed, and its key ecological components. Report cards from other systems provide a useful precedent for how to build communication vehicles from the targets and performance measures (e.g. Dennison et al, 2007). The CA WQMC My Water Quality web portal can also serve as an example of this type of communication vehicle. Resources (people, time and money) must be dedicated to reporting in the implementation plan. While reporting is critical, data for simplified forms of reporting are not the sole drivers of what is monitored and assessed.

Models

Conceptual and numerical models integrate and describe the current understanding of system components, processes, interconnections, and dynamics. The use of models is essential to understanding UMARPs IEAs. They can be used to explore how a system might respond to changes. They help define important system attributes that require monitoring and serve to explain the choice of management targets and environmental indicators. Many modeling efforts have been carried out in the Bay-Delta. Of note is the comprehensive set of conceptual models recently developed as part of the CALFED Delta Ecosystem Restoration Implementation Planning process (DRERIP). Many models are already adequately developed to evaluate and address monitoring and assessment commonalities and gaps.

Data management

Data management is an important part of a UMARP. Data management requires decisions about the goals, the audience and the structure of the data management system. Most importantly, data management requires a commitment to a core set of principles for managing data from all agencies and institutions that gather data. Once that commitment is achieved, an accessible home for the monitoring data relevant to the UMARP goals can be established. The audience most interested in the raw database of variables and metrics relevant to UMARP is the technical community, although access by the public will also be possible. Several data management systems are currently under design in the Bay-Delta. For example, the California Environmental Data Exchange Network (CEDEN, http://www.ceden.org/) has a centralized database structure designed to accommodate water and environmental data from many data suppliers and users. Data is uploaded to four data nodes according to established protocols, and then the data are made publicly available via a common website. The IEP's current database redesign places more emphasis on metadata for its different types of monitoring data, with links to a distributed network of original databases. Data from IEP and CEDEN databases will also be made accessible through the new "California Estuaries" portal of the CA WQMC, along with question-driven data interpretations. An important part of the implementation of UMARP will be to develop approaches that coordinate with and take advantage of the progress that has already been made in this important area.

New monitoring or studies

Although the Bay-Delta ecosystem has a multi-decadal history of monitoring, not all data that are likely to be useful to UMARP are necessarily being collected. New opportunities exist for enhanced monitoring, especially where research has demonstrated the feasibility of monitoring particular variables. There are also some gaps in what needs to be monitored, and in the development of metrics to address the grand challenges. A coherent program for filling those gaps should be an important part of UMARP implementation.

Building a sense of common purpose

Building a sense of common purpose among the distributed programs and a sense of common ownership of monitoring data across the Bay-Delta and its watershed is critical to a sustainable UMARP. The exercise of developing a monitoring framework will not

be perpetuated, unless the framework is understood and accepted by the wide array of parties with a stake in monitoring the Bay-Delta system. A successful plan must be integrative not only scientifically but institutionally and in a participatory sense. In the early stages, iteration between discussions and development of proposals in the small UMARP core group are being followed by discussions with the broader groups. This iteration will be crucial in the evolution of the UMARP. For example, close contact with the Science Program, the ISB and existing monitoring efforts, especially the Interagency Ecological Program (IEP), should be ongoing; partly because all of these entities could be evolving as California's water strategy evolves. Ultimately, implementation and perpetuation of UMARP will require a multi-institutional governing board to link stakeholders, observations, modeling, analysis and cyber-infrastructure under an effective multi-institutional umbrella. Specific participants in past meetings provide an example of the partnerships that will be essential as UMARP evolves:
Bay-Delta Science Program
Independent Science Board
Bay Delta Conservation Program
Interagency Ecological Program
Central Valley Water Boards,
Ecosystem Restoration Program,
San Joaquin and Sacramento River watershed monitoring groups.
San Francisco Estuary Institute
California Water Quality Monitoring Council

UMARP strategic plan

Full UMARP development and implementation will be based on a strategic plan, the development of which is an important goal of the second stage of UMARP Framework development. Important considerations in the strategic plan include:

- Continuation of the UMARP Core Committee (CC). The UMARP CC developed UMARP Framework to date. This report represents the first stage of the UMARP CCs work. In the second stage the CC will continue refining the framework and communicating the committee's progress to interested parties outside the committee. Close contact with the Delta Science Program and ISB and with existing monitoring programs such as the IEP should be ongoing as will presentations to other stakeholders as requested. A UMARP website will be developed in the second stage of development.
- Specialists and specialist subcommittees will be necessary to build from and add to particular areas of emphasis. Committees of discipline experts and discussions among implementing agencies will provide the final level of detail for implementation.
- Objectives and data needs should be periodically re-examined, as with any monitoring, assessment and reporting program and the strategic plan should include provisions for program review and refinement.

- Implementing and perpetuating UMARP will require a funding source, an institutional context, and an unambiguous leadership structure that meshes well with multi-institutional governance. For example, day-to-day implementation will require a leader or small group of leaders, the composition of which will be developed in consultation with interested parties as the strategic plan develops. The multi-institutional governance structure might include a board which we might term *the Technical Advisory Group for UMARP (TAG-UMARP).* The function of the TAG-UMARP will be to link stakeholders, observations, modeling, analysis and cyber-infrastructure under an effective multi-institutional umbrella. The TAG-UMARP will maintain a broad overview.
- Quality assurance and quality control are critical, and an *ad hoc* committee should oversee QAQC within the monitoring program(s).
- Ongoing, iterative reviews, workshops and group discussions will be a necessary ingredient to build from the initial framework in this report. An ongoing, continuous dialogue is crucial among key agency, academic, and stakeholder groups, to solicit ideas and ultimately, build toward common ownership of the monitoring, assessment and reporting.
- The present report represents the first stage of UMARP development. More immediately the next stage will entail:
    - responding to reviews of the present report and consideration of those reviews in advancing the design of UMARP;
    - defining the constraints and details of the surveillance networks that will underlie the IEA's discussed in this report;
    - considering additional IEA's
    - developing cross-cutting matrices that directly address Grand Challenges like Climate Change (building off Cloern et al, in review) and restoration (in progress by CC);
    - characterizing a realistic budget and using that to constrain the greater UMARP plan to something that seems realistic to implement.
    - designating specialists and specialist subcommittees that will define the details of implementing the monitoring (where data are available; when/where to monitor; refinement of metrics and measurements) for each IEA, and defining the agendas of those committees;
    - defining the detail of a reporting system and then designing and writing a proposal that would define a pilot program(s) for small scale experimental implementation of monitoring, assessment and reporting;
    - conducting detailed discussions throughout this process with the various interested parties and experts is essential, to assure coordination in developing technical details, budgets and governance.

- Developing a proposal for support for a postdoctoral associate to pilot a program that will explore approaches to reporting in one or more settings, employing the UMARP Framework to obtain and assess the data. For example, the San Joaquin River basin would be an excellent case study given the many changes planned for that system and the substantial number of programs planned or underway.
- A second proposal is to support for a graduate thesis to explicitly focus on the question of redundancies in existing efforts across the watershed and to find opportunities to fund data gaps through greater efficiency, rather than relying only on new sources of funds.

APPENDIX: UMARP

Identifying Important Environmental Attributes for the UMARP

The Framework provides guidance and examples as to how, where and when data are collected. Indicators, metrics, and measurements are chosen to be indicative of what is expected to change in both the short term and the long term in association with the Grand Challenges. They include both slow-responding and fast-responding metrics, i.e. those that respond quickly while trends in slower responses are developing. Existing conceptual models such as the DRERIP models provide a critical context in selecting important IEAs and and their indicators, metrics and measurements. Some variables and processes will be monitored or studied purely for the purpose of explaining the status or trends in other variables or processes (examples to follow). Criteria are used to objectively constrain explanatory monitoring to limit expansion of the program. Unexplained monitoring results will be examined through research recommended by the UMARP program. Critical gaps are also identified, particularly gaps in the data necessary to address the Grand Challenges. The details necessary for implementation will be developed in later stages by experts (specialists and specialist subcommittees).

The first step in developing a monitoring core for a UMARP is to identify the most important environmental attributes (IEAs) of the ecosystem (Dennison et al 2007). Many attributes have been repeatedly identified as critical by various stakeholders, local experts, and managers, beginning with the ERPP in the 1990's and continuing most recently into the BDCP process. But the Grand Challenges focus UMARP on understanding responses to disturbances (human and natural), policy changes, and directional changes in natural conditions.

In this report four groups of fishes are identified as examples of IEAs that integrate key ecosystem processes.

- Anadromous salmonids are iconic fishes for the Bay-Delta whose life history integrates processes across the entire ecosystem.

- Native pelagic/mobile fishes, represented by delta smelt, longfin smelt, and Sacramento splittail, are icons as well. The well-being of these species is threatened by a variety of human disturbances. Although the relative importance of those disturbances is not well known, the declining populations of these organisms probably is an integrated response to several of these disturbances.
- Fishes with a constituency include two higher trophic level predators: largemouth bass and striped bass. These are introduced species that have become sport fishing icons, and therefore support considerable economic activity. They may be a threat to some native species upon which they prey.
- Sturgeon are native species that probably are declining (white sturgeon) or are listed as endangered (green sturgeon). They are long-lived, low-fecundity species capable of bioaccumulating important pollutants in the system. Unlike the species above, sturgeon generally integrate benthic ecosystem processes.

The four groups of IEAs listed above include nearly all the aquatic species identified by the Bay Delta Conservation Plan (BDCP) as "covered Species", whose conservation and management will be provided by the plan in the form of biological goals and objectives. BDCP also identifies a number of terrestrial/riparian species that are "covered", some of which could be considered as potential IEAs. Other possible IEAs include migratory birds, human health (mercury), drinking water, and water supply reliability. But the discussion that follows will focus on the four groups of fishes as examples of how to populate the UMARP framework and as an illustration of the strategic approach.

UMARP must ultimately constrain the number of indicators, metrics, and variables to a set that is manageable and cost-effective to monitor, assess and report on. Therefore a strong justification is required for each choice. Justifiable indicators, metrics and variables fit the following criteria.

- Clearly fit monitoring goals.
- Are of primary importance to the well- being of one or more IEAs, or to processes that support the IEAs.
- Have a high signal-to-noise ratio.
- Help populate models of the system.
- Are feasible to monitor and interpret with minimal ambiguity.
- Are cost-effective.

Feasibility and cost-effectiveness are ranked as follows:

Type one: Proven feasibility, data exist

Long-term database exists for the variable(s) or metric(s).
Metrics have been calculated and trends established

Type two: Proven feasibility, but few historic data

Methods are established and data are just beginning to be collected.

Type three: Probably feasible but little precedent

Methods would require development, although research has demonstrated feasibility.

Relevant interpretations of metric seem feasible but experience is lacking.

Type four: Not yet feasible

Research is necessary to establish feasibility. Cost to establish and or perpetuate monitoring is excessive.

Thus, each indicator selected for the final monitoring program should be amenable to long-term data collection. The best indicator is one for which a history of data already exists, providing a historical perspective in which interpretation can take place. Metrics for which data are already being collected will yield immediate returns. There are also opportunities to develop new metrics from existing data or by making modifications to existing monitoring. In some cases metrics can be developed as the deviation from an observed or calculated value from a predicted value based upon quantitative models (e.g. longfin smelt abundance predicted from Delta outflow or X2). The metrics should also include a range of response times to environmental drivers. Some metrics (e.g. physical variables) respond quickly to environmental change while others (e.g. populations of long-lived fish) may respond slowly and in more complex ways.

There also are some metrics or variables for which methods might require additional development, but they are sufficiently creative, integrative or important to the IEA that rapid development is justified. However, if extensive research is necessary to establish what or how to monitor, the choice was rejected for use in the current version of UMARP.

What follows is a series of matrices with accompanying text that illustrate choices of variables and their respective metrics and indicators that could be employed to follow changes in the previously described IEAs for the Bay-Delta. Each matrix is designed to tell an independent story about an IEA or an aspect of an IEA. A chain of reasoning connects the measurements, metrics and indicators and connects indicators to the Grand Challenges.[1]

Anadromous Salmonid fishes

Issue

Salmonids, of the genus *Oncorhynchus*, are an icon representing human connections to the Bay-Delta, its watershed and the oceans, aside from being an important commercial resource. Anadromous salmonids have experienced severe declines in the past several decades, culminating in a ban on commercial fishing in 2009. Several runs are either listed under the Endangered Species Act or are candidates for such listing. Central Valley salmon in general, and individual runs in particular, are therefore of special concern due to the growing possibility of extinction. Their response to the Grand Challenges will be a broad overall indication of changes in the status of the Bay-Delta.

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[1] The accompanying text often cites Brown (unpublished) meaning Randall Brown who we have included as an author on this report. Before his untimely death, Randy had mostly completed an extensive draft on a proposed new monitoring scheme for the Bay-Delta for SNL when he was Lead Scientist. Although not quite complete the report was very insightful, being derived from Randy's long experience with California water and his leadership of CMARP. We have used that report extensively in preparing explanations for (and in some cases choices of) indicators, metrics and measurements.

Salmon populations are generally described by the season in which the adults return to fresh water. In the Central Valley, there are now fall, late fall, winter, and spring run Chinook salmon; and winter run steelhead (Williams,2006)

There are several potential causes of the decline in anadromous salmonids, that must be considered in monitoring of their status. These range from changes in headwater habitat, to rearing conditions in the Delta to ocean conditions. Salmonids are the focus of many restoration efforts on one hand. On the other their migration routes and rearing grounds in the Delta are vulnerable to change if Delta water infrastructure changes, and they are vulnerable to shifts stream temperatures that could exceed their tolerances should climate change take the trajectory projected by at least some models. Thus salmonids are an IEA that link to several Grand Challenges.

Although there are a number of excellent reviews of salmonids in the Bay-Delta available (e.g. Williams, 2006), Bernstein (2002, unpublished) most succinctly cited the potential stressors for salmonids. "Salmon runs on the Sacramento and San Joaquin Rivers have been affected by a combination of factors, beginning in the mid-1800s, when hydraulic gold mining methods resulted in severe sedimentation in many streams. In addition, the population increase in California during this period was associated with a large increase in salmon harvesting, the development of large salmon canneries, and overharvesting. … the construction of dams for water diversion and storage, the beginning of water export operations in the Delta in the 1950s (federal Central Valley Project) and 1960s (State Water Project), and continued habitat degradation from a variety of causes (e.g., instream gravel mining, flow modifications, physical disturbance from recreational activities) have reduced available habitat, increased mortality of both adults and juveniles, and led to excessive predation in some locations (Figure 1).

Conceptual Model

Many conceptual models have been developed for salmonid fishes, but the model presented below (from Brown, unpublished, after Kimmerer) generally indicates how the life cycle interacts with environmental factors that determine the status, overall, of anadromous salmonids in the Bay-Delta watershed. Williams (2006) described the life cycle as follows: In general, "*Oncorhynchus* all spawn in fresh or brackish water, burying their eggs in gravel nests called redds where the eggs incubate. The redds protect the eggs, and *Oncorhynchus* have relatively few (usually <10,000), large eggs. The young hatch as alevins, larvae with a large egg yolk attached to their bellies. The alevins grow and develop in the gravel, living on egg yolk rather than feeding, and emerge as small fish about the time the egg yolk is fully absorbed…When the yolk is nearly depleted and fully enclosed in the body…they become simply "fry." They become "parr" when they develop dark vertical bars or parr-marks on their sides. Larger juveniles migrating toward the sea become silvery and are called "smolts."

"Most species of *Oncorhynchus* are at least partly anadromous… Chinook salmon may rear in streams for a few days to two years, and spend a few months to seven years at sea… Central Valley Chinook forage primarily in coastal waters off California and Oregon, and Central Valley steelhead may do so as well…Since these fish grow mainly in the ocean, they carry nutrients from the ocean to streams that benefit juvenile salmon and other aquatic organisms…"

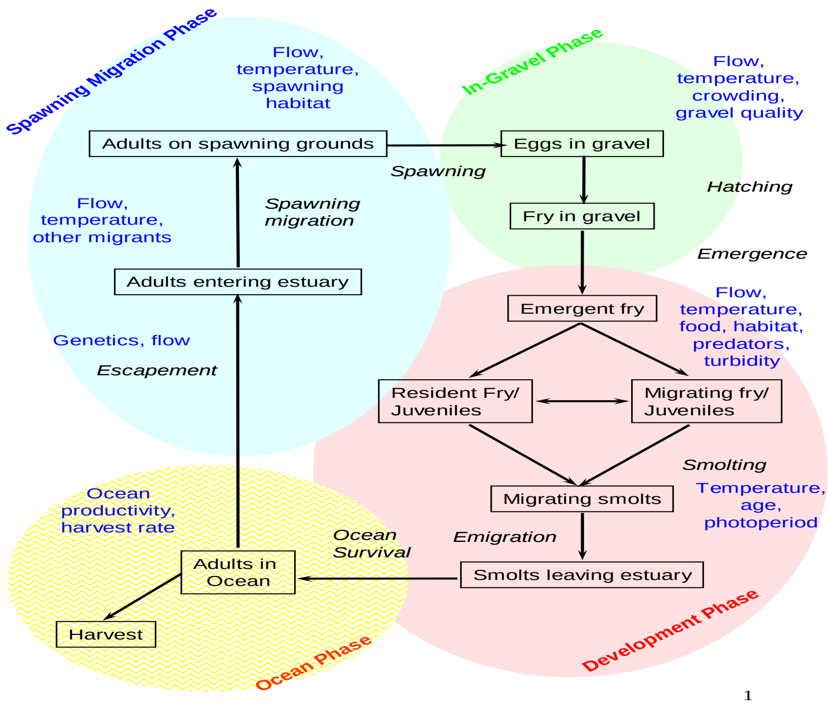

Figure 2. Conceptual model for anadromous salmonids (Brown, unpublished).

Indicators of salmonid well being

In assessing salmonid well-being, it is necessary to consider: a)abundance, b) success at different life stages, c) habitat and d) stressors. Each (or some) life stage occupies a different habitat and some stressors differ among habitats. Indicators specific to each habitat are therefore necessary to track critical elements of the complex life cycle. In setting ecosystem goals and objectives for salmonids, the Bay Delta Conservation Plan (BDCP) cites critical habitats as:

- freshwater spawning sites,
- freshwater rearing,
- freshwater migration corridors,
- estuarine areas with water quality, water quantity, and salinity conditions supportive of juvenile and adult physiological transitions, and
- nearshore/offshore marine areas.

To differentiate different processes in different habitats, UMARP differentiates two sets of indicators geographically: tributary indicators (freshwater spawning and rearing) and main stem river (e.g. Sacramento and San Joaquin)-delta-ocean indicators. While the goal is to select a constrained set of indicators, metrics and variables for the two habitat types, we recognize that more detailed surveillance networks must underlie these indicators. In each case a table of core indicators is presented that should “tell a story” about responses of salmonids to environmental change, when the data are regularly assembled and interpreted. But each story builds from data collected in the (often distributed) surveillance networks. The word “tributary’ is, of course, sensitive to scale. For UMARP a “tributary” is defined as each major tributary with a confluence with the Sacramento or San Joaquin Rivers. These provide the largest scale integration of processes occurring across each major watershed.

Tributaries: Salmonid indicators, metrics and variables

It is important to monitor, assess and report over time on how the contribution of each major tributary to salmonid populations in the Delta is changing and why. The focus of most activities in the first decade of the 2000 millennium has been on the Delta, as the nexus where environmental and water supply reliability issues intersect. But it is widely agreed that tributary watersheds are just as important, if not moreso, than the Delta in determining the well-being of anadromous salmonids. From a Delta-centric view we might view each tributary as contributing salmonids to the Delta, and to the overall status of water issues in California.

One of the models for UMARP is the Moreton Bay, Queensland situation, where successful monitoring and reporting scheme in both local tributaries and Moreton Bay combined to address management of nutrient inputs to the system (Dennison et al 2007). Dennison et al (2007) observed that one reason for the success of Moreton Bay monitoring program was that obtaining good grades on their contributions to the Bay was a serious local responsibility for each watershed. In some sense competition began to develop among the watersheds as to which provided the highest quality water to Moreton Bay.

In the San Francisco Bay-Delta each watershed also has its interest groups. Bottom up social drivers of this sort could help perpetuate a UMARP, if some base of funding for local efforts could be provided. The goal of the UMARP matrices below is to provide guidelines for each watershed as to the crucial data to assemble in order to conduct its own annual assessment and reporting on its contributions to the Delta. Nearly all the indicators, metrics and variables in these tables represent data that is already available, or could be easily assembled, albeit from a variety of sources. Local groups have much broader interests than just salmonid populations, of course. The framework provides a starting point from which each local interest group might build-on additional monitoring, assessment and reporting, for local or regional purposes.

Local management, restoration activities and climate change will all affect the contribution of each tributary to the Delta in the future, just as climate, Delta management and ocean conditions will affect the return of salmonids to each tributary. The indicator system is built to assess changes in all of these. Each major run of Chinook salmon also has some characteristics that are unique. Therefore run-specific modifications to the basic set of indicators are presented in Table 2. Table 1 presents 19 indicators that could allow tracking anadromous salmonids and factors that could influence them, in response to the Grand Challenges.

Table 1. Monitoring in each major tributary of the Sacramento and San Joaquin Rivers.

Purpose	ASSESSMENT	EVALUATION	MONITORING	Feasibility, Relevance
	INDICATORS	METRICS	MEASUREMENTS	
Salmonid abundance in each tributary**	Escapement: trend through time	Size of spawning population (annual)	Number of redds (weekly counts); Carcass surveys	1, 1
Fecundity	Egg production; Reproductive potential	a.Number of spawning females b.Fecundity c.sex ratio	Abundance, size, age, gender, condition	1, 1
	Hatchery contribution	Hatchery releases	Number of hatchery fish released	1
Reproductive success	Outmigration	a.Juvenile outmigration b. hatchery fish/total juvenile pop.	Number of outmigrating juveniles (e.g. screwtrap number or index)	1
Population projections	Future population size	Calculate from number of two year old "jacks" fish	Adult: abundance, size, age, condition	1
Hydrology	Precipitation	Cumulative daily totals	Areal over watershed (DWR)	1
	Contribution of snow pack	Annual cumulative total snowfall Water content of snow	Regular snow measurements from DWR	1
Flows	Internal role of reservoir storage	Low points in reservoir storage. When & how often below a certain level.	*DWR & BR data*	1
	Extent and duration of inundation below reservoirs	Reservoir discharge.	*DWR & BR data plus USGS downstream gage data*	*1*
	Dewatering	a.Days stream is below critical	Streamflow from gages Studies on	1

		minimum passage threshold during critical season. b. Flood frequency	adequacy for passage.	
	Temperature	Number of consecutive days in migration period (and corridors) when temperature is above lethal threshold Days of lethal temperatures	Daily temperature Data on lethal thresholds	1
	Diversions and impediments	a.Cumulative number of obstacle days or days structures in stream impede passage. b.Cumulative volume of water diverted and c.proportion that is screened.	Number of diversions Volume of diversions Number of impediments to passage at different stream flows. Migration data	1
	Biological suitability & habitat	WSA biotic index for selected small streams	Benthic data from SWAMP surveys of wadeable streams	3
Suitability of habitat	How much habitat suitable for spawning	Area and suitability of gravel within area of suitable temperature	Multiple measures of area of suitable gravels, (once per 5 yrs.)	2
	Stream habitat (adequacy for	Some index of biotic integrity	Rapid bioassessment for	1

	salmonids)		three years, then once every three years	
Stressor: Hatcheries	Influence of hatcheries	% returns of hatchery origin (Returns of hatchery origin/ total population)	Number of hatchery returns. Coded wire tag in hatchery returns and carcasses. Otoliths in future.	1
Stressor: Contaminants	Pesticide inputs	Kg of each category of pesticide used/ seasonal cumulative stream discharge?	Pesticide usage in buffer zones; Stream discharge	1
	Biomarkers for young life stages of salmonids			3
Influence of restoration	Restoration actions (overall)	Use restoration table to implement as approporiate for this circumstance.	Cumulatively document and value specific actions completed	2

*Randy Brown monitoring proposal lists important reservoirs
**R = aerial surveys; P = data gap in monitoring; C: Mark recapture survey on carcasses.

Abundance

Abundance is the best estimate of population size for salmonids and is the ultimate response to environmental conditions. Abundance data are fundamental to some crucial policy decisions, such as whether or not to list the species or run under the Endangered Species Act. Monitoring abundance entering and leaving a tributary is the first step in separating upstream effects from corridor, nursery and ocean effects.

The purpose of monitoring abundance is to track trends through time, and to address whether those trends are meeting pre-established criterion (e.g. upward trajectory). The substantial data that already exist show that trends can be complex. In some cases they are dramatically positive (e.g. Butte Creek Spring run salmon), or negative (e.g. trends in Winter Run before 2000; recent trends in Fall Run). Interpretations can be strongly influenced by the time scale chosen for analysis, however (e.g. Tuolomne River). In general trends are typically more complex than simply positive or negative.

Data on abundance are primarily based on measures of "escapement" which is defined as the number of adults that return to a stream to spawn. This is developed from observations of number of redds, carcass surveys, or in some places surveys of adult abundance (e.g. snorkel surveys). Although abundance data is collected in almost all tributaries, different data might be collected in different streams. Differences in methodologies for the same approach might also occur among tributaries. While some of these differences are dictated by physical differences and practical considerations, a major concern is inadequate coordination of methods among tributaries and, in many cases, inadequate documentation of methods necessary to assure coordination (Brown, unpublished). Calibration across techniques and consistency across tributaries is an (achievable) goal of UMARP and is essential to comparisons among tributaries. For example, making data more comparable among tributaries might ultimately allow an overview of the relative contributions of each tributary to the migrating populations of each run of salmonids in the Sacramento and San Joaquin Rivers.

Improvements in methdologies are also possible. The Stanislaus river wier project is an example, where hourly passage water quality data and other data about the fish are collected in a systematic manner.

Text Box. Abundance
Why. Track trends in population size through time.
Target: Targets are run-specific and, in some cases, tributary specific. Adequate numbers to open ocean fishery.
How and Where collected: Redds, carcass surveys, screw traps, snorkel surveys. All tributaries, but some differences in methods.

Abundance needs to be combined with other data to provide even the simplest understanding of trends and why they might be occurring. Data on individuals such as size, sex, age and condition can lead to projections of fecundity, the sex ratio or the cohort replacement rate (a measure of how spawning success is linked to overall population size). Other useful data include the ratio of the area of redds/number of redds, which can provide an estimate of habitat suitability, allow development of a crowding index, or indicate how much of available habitat is being used.

Knowledge of inputs to the population from reproduction and hatcheries, and estimates of the resulting number of outmigrating juveniles allow measures that facilitate understanding of the trajectory of the population. Egg production is one important measure of reproductive success of the spawning population. The number of fish released locally by hatcheries is another input in some streams (some hatcheries release their juveniles downstream in the Bay-Delta, however). The outcome from these inputs, and the factors that influence them, is juvenile production, determined by the number of outmigrating fry, smolts and yearlings (Williams, 2006). Juvenile production is a function of the number of adults coming back and the success of their reproduction; thus it is an integrative indicator of many stream processes. The relationship between number of adults returning and number of juveniles is another metric useful to better understanding the influence of the various processes that determine the success of salmonid production in a stream. The juvenile production Index or JPE gives an estimate of the number of eggs produced by females versus the surviving juveniles. The JPE and related measures allow projections of the trajectory of the population and are used decisions regulating ocean fisheries. Different methods are employed in different places to provide these metrics. Again, there is a need for better consistency in methodologies among tributaries and better documentation of methods in each tributary to facilitate that consistency.

Text Box: Fedundity and reproduction success
What. Inputs from reproduction and hatcheries, outputs measured by outmigrating juveniles, characteristics of immigrating fish.
Why. Data show trajectory of population. Used in regulating ocean fishery.
Target
How. Keswick and Red Bluff screw traps for juvenile outmigrating Winter Run; screw traps on some tributaries provide data on Fall Run. Hatcheries provide number of hatchery fish returned to the system, carcass surveys provide data on individuals. Future population from number of two year old jacks.

Juvenile abundance and emigration timing are estimated by use of screw traps on some streams to catch and count fry, smolts or yearlings. Ultimately if comparability among tributaries could be established among measures of outmigration of juveniles, then it might be possible to estimate the relative contribution of each tributary to total salmonid migration into the Delta. Such information could be useful in prioritizing decisions such as where to locate restoration projects and would facilitate addressing questions like whether multiple populations add stability to a run of salmonids. The weakest aspect of this measure is that trap efficiency data are not very reliable (Brown unpublished). Brown recommended against using this as a metric for outmigration because of such uncertainties.

Hydrology, Geomorphology and Stream suitability
The reproduction and well being of anadromous salmonid in their spawning and rearing habitats in the Bay-Delta watershed are at least partly controlled by interrelated aspects of the physical environment like temperature and flows. It is widely accepted that river ecosystems are dependent upon the natural variability of flow (the flow regime) that is typical of each hydro-climatic region and upon the range of habitats found within each channel type within each Region (Petts, 2009). In most, if not all, of the major tributaries from the Sierra Nevada human demands for water conflict with the needs of anadromous salmonids, both in terms of timing of water use (needs) and quantity of water needed. Hydrology will also be one of the variables most directly influenced by changes in management and changes in climate. Critical hydrologic measures and trends can provide us with immediate feedback if major changes are underway. Therefore, to understand how environmental change is affecting the status of anadromous salmonids, we must consider hyrology, geomorphology and other aspects of stream suitability. UMARP addresses the basic hydrology of each tributary from a mass balance point of view: Are inputs changing (precipitation, snow pack)? What is the status of reservoir storage and what is the downstream influence of reservoir releases?

Precipitation and snow pack

These indicators bound the amount of available water, and its form, for each major tributary. Long-term precipitation records provide data on intra-annual and inter-annual variations (including global climate change) in the amount and forms of water falling in each basin. It is likely that the existing network of precipitation stations (including snowpack monitoring) provides an adequate database for this purpose. Climate specialists should be asked to identify those stations that are essential to a longterm monitoring program.

Flow

Brown noted that the presence of reservoirs on most major Central Valley streams complicates the flow monitoring picture, but most of the streamflows above and below the reservoirs on the major tributaries have stream gages and therefore are monitored and reported daily by the agencies that operate the reservoirs for flow management, water supply and recreation. But for UMARP some integrative measures of the role of reservoir storage might be most informative. Examples include understanding low points in reservoir storage, how often a reservoir is below those low points, and the extent and duration of inundation below reservoirs get at the essence of the problem for downstream salmonids.

Dewatering is also a simple and traditional indicator of the suitability of flows at times of year when demands for water conflict. The degree of variability in dewatering is an important aspect of the metric and will differ from stream to stream and year-to- year. For example, flood flow every few years is essential to sustain physical habitat; variability is critical on an hourly to weekly time scale during egg development season. Quantitative monitoring of reservoir discharge during spawning and rearing season is the strongest driver of suitable stream habitat and suitability of the stream for outmigration.

Brown suggested that the key dammed streams on which daily flow measurements below the dams were needed are:

1. The Sacramento River below Keswick
2. Battle Creek
3. Butte Creek
4. The Feather River
5. The Yuba River
6. Bear Creek
7. The American River
8. The Mokelumne River
9. The Stanislaus River
10. The Tuolumne River
11. The Merced River

The undammed streams for which daily streamflow data were needed are:

1. Clear Creek – A Calfed AM stream
2. Mill Creek – a key spring Chinook stream
3. Deer Creek – a key spring Chinook stream
4. Cosumnes River – a major undammed streams left in the Valley

Indicator: Hydrology & Geomorphology
Why?
Establishes crucial habitat
Target
Provide largest sustainable habitat
How, where , when
Inputs: Gages, snow surveys, measurements of thermocline in Shasta. Flows: Data from when fish are present…Sept – Jun**.**

Water temperature

Water temperatures are of critical importance to a variety of physiological processes and are of particular importance to Chinook salmon and steelhead rainbow trout – two species that are near the southern end of their range. The threat of global warming increases the necessity for a long term data set. Brown suggested a baseline temperature monitoring program across the entire watershed could provide crucial information on temperature change.

- The Sacramento River between Keswick Dam and Red Bluff. Compliance sites for Shasta operation are in place and some or all of them should be maintained.
- Mill, Deer and Butte creeks. There are existing sites for all streams and they may not be all needed.
- Rim inflow stations to the Delta – the Sacramento River near Sacramento and the San Joaquin River near Vernalis.
- Internal Delta water temperature monitoring. The revised temperature monitoring stations being run by IEP's water quality element satisfy the need for Delta water temperatures. A subset of the continuously monitored stations may be adequate for the baseline program.
- Temperature of the water exported from the Delta. As will seen below, the baseline program may include additional data collection efforts at the Central Valley Project and State Water Project intakes in the South Delta. Water temperatures could be an integral part of this data collection system.
- Lower estuary water temperature. The Bay monitoring stations (San Mateo Bridge, Bay Bridge, etc) with their upper and lower depth monitors can provide an adequate longterm record. As with the Delta stations, a subset of these stations may provide the data needed to assess longterm trends.

Integrative measures

The above represents a traditional approach to monitoring stream hydrology and geomorphology. But these simple measures do not capture the complex processes that are dynamic on several temporal and spatial scales. It is the sum of those processes that actually determine the hydrologic/geomorphological aspects of stream habitat. Pett (2009) noted that the ‘‘flow regime’’ of a river is a complex concept, but two fundamental principles apply:
(1) The natural flow regime shapes the evolution of aquatic biota and ecological processes and
(2) Every river has a characteristic flow regime and an associated biotic community and

(3) the linkages between flow regime and ecological health are complex in both time and space.
He notes that the ‘‘natural dynamic character’’of the stream relates not only to flow variability but also to temperature variations, sediment dynamics, and channel dynamics (that are also influenced by patterns of woody vegetation growth), changes in food ⁄ energy supply, and interactions between biological populations.

An important part of developing the core hydrology/geomorphology program for monitoring, assessing and report change in tributaries will be to identify a very small number of indicators that allow UMARP to track changes in these inter-related processes. From principles suggested by Bunn and Arthington (1992) four examples that might comprise a package of indicators emerge:

- Flow as a major determinant of physical habitat;
- the pattern of habitat connectivity (a) along a river and (b) between the stream and its riparian zone and floodplain;
- an aspect of the life history strategy of anadromous salmonids that is particularly responsive to habitat;
- the success of exotic or introduced species (which are more successful in modified flow regimes).

Instream diversions and impediments to flow.
A stressor of potential importance to monitor in tributaries is the environmental change in the amount of water diverted from each stream and changes in impediments to migration. Diversions and impediments are common in the watersheds of the major tributaries, and could be an important source of mortality for salmonids (although few systematic studies are available). Examples of metrics that can used to track changes in water diversion include number of diversions in different volulme categories, or preferably, cumulative volume of water that is diverted along with the percent of water diverted that is diverted through screens (alternatively the proportion of diversions that are screened). Obstacles to migration are flow dependent in some streams, therefore the metric for this indicator might be the number of obstacles to migration at lower flows typical of during the migration period.

Habitat
Habitat is another fundamental driver of salmonid production over the watersheds of the major tributaries. Even if temperature and flows are adequate for spawning and rearing of anadromous salmonids, inadequate stream habitat can limit salmonid production. Brown noted that habitat was a broad categorization that could include such widely different measures as gravel quality, interstitial flow in the gravel, food resources in the streams, suspended sediment or bed load transport. Comprehensive monitoring of habitat on a periodic basis is typically an important aspect of monitoring stream ecosystems. It is important to continue such monitoring in the broader surveillance network(s), such as the California’s Surface Water Ambient Monitoring Program or SWAMP.

For its core assessment and reporting program, UMARP will focus on two critical indicators relevant to anadromous salmonids. One addresses the availability of spawning gravels in the major tributaries. Surveys of spawning gravels have been conducted in most streams but a systematic record what data is available seems lacking. It is probably not necessary to monitor gravels every year, although annual floods and large bed load transport events can both clean and re-position gravels. Surveys might be initially conducted for three consecutive years to establish variability for a stream, then the streams might be re-surveyed every third year, for example.

A second useful indicator should be an integrative measure of habitat suitability overall. Rapid habitat assessment techniques are available. However, the most useful integrative indicator might be a cumulative measure of the status of the benthic community over the watershed of the tributary. For example, SWAMP samples 75 randomly selected perennial wadeable stream reaches every year collecting data on biological condition and water chemistry. While these collections are not conducted in the major tributaries themselves, collation of the data from multiple small streams in each major tributary might provide some measure of habitat suitability in that stream. Comparisons among tributaries or changes within tributaries in stressors like mining or urbanization, for example, might be captured in these small stream data. SWAMP uses multiple measures to categorize each site as good, degraded or very degraded; and reports an index of biotic integrity. But there is the potential to employ the SWAMP data in UMARP to develop sophisticated measures that are more stressor-specific, like number of mayfly species or number of species sensitive to a particular stressor like mining. The methodologies employed are those used in the USEPA Wadeable streams (WSA) national surveys. The WSA uses *benthic macroinvertebrates* to determine the biological condition of streams. These include aquatic larval stages of insects such as flies and dragonflies; crustaceans such as crayfish; and worms and snails. Since some benthic macroinvertebrates are more sensitive to pollution than others, information on the abundance of the various types of organisms reflects the "health" of a stream. The WSA supplements information on the biological condition of streams by measuring a few chemical and physical indicators that reveal stress or degradation of streams: four chemical indicators (phosphorus, nitrogen, salinity, and acidity) and four physical condition indicators (streambed sediments, in-stream fish habitat, riparian vegetative cover, and riparian disturbance). From the combination of biological, chemical and physical measures, a biotic index can be calculated that characterizes each wadeable stream. Several of these indices from a watershed can contribute to the story about the state of habitat in a tributary's watershed.

What?

Stream bed gravels; biotic index of stream condition.

Why?

Even if temperature is right, without habitat no successful reproduction. Must monitor because gravel and habitat suitability are not constants.

Target

Assess if there is not suitable habitat where other conditions are suitable.

How, where, when collect data

Every three years. Where is determined by otherwise suitable conditions
<u>How</u>
Established assessment techniques from F&G for gravels and SWAMP for biological condition.

Effect of Hatcheries

Hatcheries were developed in the Bay-Delta watershed to mitigate for disruption of access to upstream breeding habitat by dam construction and to supplement populations that were not self-sustaining. Therefore the proportion of hatchery raised fish that return to hatching and rearing habitat is a metric for evaluating the self-sustaining capability of the natural population. As the proportion of hatchery fish in the population declines it is sign that the population is approaching self-sustaining status; and vice versa.

Fall-run are raised in five hatcheries in the Central Valley: Coleman (Battle Creek), Feather River, Nimbus (American River), Mokelumne River, and Merced River. Williams (200) estimated that about 24 million juveniles are released annually. The Coleman and Merced hatcheries release most of their production up river. The Feather and Nimubs hatcheries release essentially all of its production in the San Pablo Bay as smolts. The Mokelumne Hatchery releases some as smolts in Mokelumne River, some as yearlings in the Mokelumne and a significant fraction (the "enhancement" production supported by the ocean fishing industry) is released in San Pablo Bay (Brown).

In the past decade or so, many of the hatchery fish have been marked with coded wire tags to identify the fish when they are recaptured in the Delta, the ocean fishery and on the spawning grounds. The fraction of fish tagged varies from year to year, but by hatchery it is approximately:

Coleman – 5-10%
Feather – 5-10%
Nimbus – mostly 0% but some fish were tagged the past two years.
Mokelumne – essentially 100%
Merced – essentially 100%

The return data from releases of these marked fish are analyzed with the goal of estimating the fraction of spawning fish that are of direct hatchery origin, straying from one stream to another and contribution of the hatcheries to the ocean and inland harvest.

For the hatcheries where only a small proportion of the fish are marked, it is necessary to estimate the number of native fish by deriving a small number from two large numbers (the number of natives is small compared to the number of hatchery derived fish and the total). The smaller the number of fish marked, the larger the uncertainty in the estimate of hatchery fish.

In the future it is imperative that a larger proportion of fish are marked. The effort of marking all fish with coded wire tags would, in the end, probably be cost effective. But investigation of improved means of marking in the hatcheries (raising fish at an unusual temperature) could greatly improve efficiencies and provide a more cost effective means of marking all fish. The latter would necessitate use of otolith analysis to determine the proportion of hatchery fish but this technology is reasonably well developed.

Effects of contaminants

The most likely effect from chemical contaminants in most non-urbanized spawning and rearing habitats is from pesticide inputs, although mercury and mine wastes could also be issues.   For example, salmonids are known to be especially sensitive to copper, a contaminant in mine wastes that are common in some tributaries.   A number of programs exist that monitor chemical contaminants, but assessment and reporting on the data can be complex. Pesticides present a particularly difficult problem, in that a large number of pesticides are used in the watershed, and the determination of each at the concentrations that occur in nature requires complex and analytically challenging methodologies.   One integrative (although not necessarily satisfying) indicator is pesticide use in the riparian and adjacent buffer zones that surround each tributary.   More detailed chemical monitoring might build off this integrative measure, focusing on pesticides that are of the greatest likelihood to be problematic in each watershed. For example,   monitoring of pyrethroid pesticides might be desirable in either water or sediments in tributaries where heavy pyrethroid use is known (e.g. the urbanized area of the American River; Weston et al 2005). Similarly, if the integrative bioassessment described above shows streams with biological conditions indicative of mining impacts, monitoring in those watersheds might focus on targeted measures like copper in fine sediments or mercury in upper trophic level fish.

What. Pesticide use in buffer zones around rivers. Bioassessment measure from wadeable streams in the watershed.
Why. Toxicity from chemical contaminants is known to interfere with spawning and affect the well being of young life stages of salmonids.
Target. Water quality standards exist but are of limited use.
How, When, Where. Take advantage of distributed data. Water quality monitoring is widespread through the Bay-Delta watershed but systematic interpretation of the data, especially across programs, is rare. Pesticide use data are available for most tributaries, as are bioassessment data from wadeable streams in most larger watersheds.

Restoration

Every tributary should be aware of restoration. Monitoring the number of actions is a simplistic first level indicator, as would be the areal extent of proposed and implemented projects (each).   Effectiveness is also important to consider, but difficult to measure (UMARP will consider that later when we consider monitoring restoration as one of the grand challenges).   Restoration monitoring suggestions should be implemented as relevant to this particular system.

Tributaries: Run-Specific modification in tributary sampling

The general scheme will differ somewhat from tributary to tributary depending upon the run of salmon that dominates that tributary. Each tributary has a dominant run of anadromous salmonids (or at least a dominant run) and each run requires some specific and unique considerations. Winter run are assumed to dominate the upper Sacramento River from Red Bluff to Keswick reservoir, could use Battle Creek as a genetic refuge. Spring Run are assumed to dominate in Deer, Mill, and Butte Creeks. Fall Run appear to dominate in Battle Creek, Feather River, Tuolomne, Merced, Stanislaus, and the American River. Late fall Chinook are also designated as a genetically distinct unit (Williams…). Genetically late fall Chinook closely resemble fall Chinook but late fall spawn later and are generally larger than fall run. But there is currently no reliable way to estimate to the numbers of naturally spawning late fall Chinook so UMARPP is not recommending that monitoring include late fall Chinook .

Table 2. Unique environmental attributes for Winter Run and Spring Run Chinook salmon in the major tribuatries.

Run of Chinook Salmon	***Assessment: Indicators***	***Evaluation: Metrics***	***Monitoring: Measurements***	
Winter Run	Extent of suitable cold water habitat for spawning	Multi-year average minimum coldwater pool size. Minimum annual length of cold water habitat. Minimum size of cold water pool in each year.	Flows: How much water coming into pool. ..Temperature along pool reach of Sac R. ..Storage:How much water going in and out. Storage and temperature profile in reservoir.	1
	Battle Creek Restoration	% area accessible; area used by winter run	Area occupied by winter run redds	1
Spring Run	Spawning adult abundance (escapement)	Number spawning in: Deer Cr., Mill Cr. & Butte Cr.	Adult surveys by snorkel surveys	1
	Influence of restoration of San Joaquin River	Presence of spring run in SJR	Occassional survey for spring run in SJR	1

***Winter Run Salmon*:**

Monitoring winter run abundance is an essential component of UMARP mainly because of its status as an iconic MSCS species. Access to the historic upstream, cold water habitat of Winter run was blocked by dam construction. Extinction was prevented by establishment of a cold water pool in the Sacramento River below Shasta, derived by pumping cold bottom waters from Lake Shasta into the river below the reservoir. A recovery goal exists; at least originally it was an average of 10,000 female spawners a year over a 13 year period. Restoration goals involve establishing a refuge for the Winter Run genetic unit in Battle Creek.

UMARP focuses monitoring on the general salmonid-specific measures cited earlier; but the monitoring of stream condition focuses on the cold water pool region, and whether or not there has been any success in establishing Winter run in Battle Creek (access is currently blocked by an impediment at the downstream hatchery on Battle Creek). Recent studies by DFG have demonstrated that carcass surveys can provide reliable abundance estimates. The animals spawn in the summer and thus are relatively easy to find. All hatchery fish are marked. Therefore the percent hatchery fish in the populations can be estimated (Brown). The USFWS screw trap studies below Red Bluff Diversion Dam have provided estimates of the numbers of juveniles leaving the spawning ground and the timing of this emigration. Service staff has done a good job estimating trap efficiency making the estimates reasonably reliable from a statistical sense. Take at the export pumps is (or at least was) limited to 1 – 2% of JPE; thus the latter is an important metric to monitor over time. A primary Winter run-specific habitat indicator that needs to be reported on systematically is the extent of suitable cold water habitat for Winter run. The minimum size of the cold water pool in the Sacramento river is an example of a useful metric. This metric can be derived by monitoring temperatures, flows and some reservoir characteristics. Access of Winter run to Battle Creek also should be considered periodically. There are no winter run in Battle Creek as yet, probably because of impediments to migration, but establishing a population there is a goal.

Spring Run

Spring Chinook are restricted to the Sacramento Basin are also an MSCS species. Spring-run were extirpated in most rivers by mining or dam construction. Populations that are thought to be self-sustaining now survive only in three tributaries of the Sacramento River: Mill, Deer, and Butte creeks. Small populations also occur in several other tributaries (Williams, 2006). Mill and Deer Spring run are apparently one genotype and Butte Creek another. Estimating the numbers of adult spring Chinook is difficult because of the relatively low numbers of fish and the difficult terrain in the major streams where they occur. Counting live adults, usually by snorkel survey or aerial observation, appear to be the best available measures of abundance (e.g. data from redds are unavailable). The challenges of monitoring these streams may limit the availability of data for measures of reproductive success, habitat and stressors. Brown suggested that Butte Creek offers the best opportunity for robust monitoring of trends in an at least partly successful spawning environment. The number of spawners are measureable, the run is genetically distinct and many changes have been made in Butte Creek to improve salmon habitat and fish passage. Estimates from Mill and Deer Creek could reflect influence of restoration, should such activities could increase in those habitats. The target for each stream is set by the number of fish that each can support (estimate). Improved documentation of the stream-specific methodology for establishing the abundance of spring run would greatly benefit monitoring, assessment and reporting for this species.

Fall Run

Fall run Chinook salmon live in lower elevation waters and dam construction has not eliminated as many breeding grounds as it has for other runs. They are or could be monitored in Battle Creek, as well as the Feather River, Yuba, American, Mokelumne, Stanislaus River, Tuolumne River and Merced Rivers. Monitoring Fall run Chinook salmon is essential because they support the ocean fishery. The AFRP has set a goal of doubling the population of naturally spawning Chinook salmon including the fall run. To

Most tributaries estimate abundance of fall run by carcass surveys and/or number of redds. Some places count adults. The methodologies for each tributary differ and the differences are not well documented. Overall assessment of fall run populations across the tributaries is complicated by the large differences in approach to monitoring including differences between the Sacramento and San Joaquin basins. Coordination and communication could be used to facilitate monitoring each stream in a systematic and comparable, if not consistent, way in the future. The poorly known effects of the large numbers of hatchery fish released also add complications to interpreting Fall run populations. The spawning population data is available in a spreadsheet entitled Grand tab, but it is unclear in that data if and how the differences in methodologies are accounted for.

Brown noted that "juvenile abundance and emigration timing is estimated by use of screw traps on some streams. Most of these trapping operations have attempted to estimate trap efficiency with varying degrees of success but estimating escapement for the natural population would require tagging all hatchery fish (or at least a constant fractional marking program; Brown). In the Sacramento watershed, the USFWS screw trap studies below Red Bluff Diversion Dam provide estimates of the overall numbers of juveniles leaving the spawning ground and the timing of this emigration."

At present, the hatcheries on Battle Creek, and the Feather, American, Mokelumne, and Merced rivers together produce and release more than 20 million juvenile fall Chinook each year (Brown). It is widely recognized that monitoring the proportion of hatchery fish is crucial to monitoring this run, and that current estimates are highly uncertain because of the inconsistencies in the tagging programs. Improving the latter is essential to a long-term UMARP for anadromous salmonids. It is also important to supporting the analyses needed to turn the information into annual estimates of hatchery contribution to ocean catch and proportion of spawners that are of hatchery origin.

Rivers, Delta and Oceans: Anadromous Salmonid

Tables 3 and 4 shows general choices of indicators for a unified monitoring of salmonid populations in the critical habitats downstream of the tributaries. Migration corridors, suitability of the estuarine nursery and ocean factors are each considered. The tables are broken into endogenous environmental attributes (Table 3), which are attributes of the salmonids themselves and exogenous attributes (Table 4), which are environmental conditions that influence the population.

Table 3. Important Endogenous Environmental Attributes for monitoring, assessing and reporting on anadromous salmonid fishes in the migration corridor and the oceans.

Critical Habitat	*Assessment: Indicators*	*Evaluation: Metrics*	*Monitoring: Measurements*	*Feasibility*
Migration corridor: Rivers and Delta	Fish flux toward the sea (juveniles), determined by reach specific survival[3]	*a.* Number of fish passing a selected location per day; b. progressive counts landward-to-seaward; c. Survival between sampling points.	a.Rotary screw traps (Tribs & Red Bluff-Winter run); b. Trawling (Sacramento, Freeport; Yolo Bypass;Mossdale, Chipps Is.) c. Acoustic tag experiments[2] d. pattern recognition[5]	2
	Run and reach contribution to migrating salmonid populations at different times	a. Number & size at date from each river/stream; b. Genetic analysis[5] b. Otolith micro-chemistry	a. Counts and size of fish in traps and trawls; b. Otolith micro-chemistry on selected fish	2
	Fall run access to Bay: San Joaquin	a.SJR flow/exports	SJR flows at Vernalis & Stockton (when); Exports (when); Barrier in or out	1
	Fall run access to Bay: Sacramento	Sacto: % time OMR is negative. Sac R. Flow	Sac R. flows at Rio Vista Condition of Delta Cross Channel OMR flow	1
	Adult migration corridor: Connect Bay to SJR	Each Yr: Are there 10 days with inflows >1/3 of exports in Sept. & Oct.*	Exports relative to inflow at Vernalis	1
Suitability of Estuarine Nursery	a. Delta rearing	a. Fish per unit time migrating seaward past Chipps Island compared to fish entering the Delta. **Once per year:** b. Acoustic tag experiments. *c. Otoliths to characterize growth & identify % fish that reared in Delta.*	a. Chipps Island salmon numbers by race and origin; b.Mossdale (Sacto R.) outgoing numbers; c. Outmigrants from Red Bluff; d. Acoustic tagged experiments: annual. e. Otoliths: Sr/Ca, growth, how long in Delta	2 3
Ocean factors	Ocean conditions	Stage of PDO; El Nińo; NPGO	Ocean factors used to calculate ocean cycles	1

Salmonid flux toward the sea

Fish flux or the number of seaward-bound fish passing a selected location per day can allow an estimate of reach specific survival through the rivers, and delta survival. These are two very important measures to identify potential problems in the migration corridor in an integrated fashion. The NRC 2010 review of the Biological Opinions called for this type modeling approach to make use of existing data.

What . Fish flux or survival between specific points in the migration corridor.
Why. Understand contribution of each component of the migration corridor to salmonid survival.
How, where, when. Employ existing screw trap and trawling data, and existing flow measures to do calculations. Should involve adjusting fish sampling to make more suitable to this additional goal.

In the rivers fish flux measurements can be derived from collections with rotary screw traps. At the Red Bluff Diversion Dam trapping effort has been high and calibration of the traps has focused on estimating the numbers of fish passing the dam. Red Bluff is a prime location for measuring the flux of winter Chinook because nearly all of the spawning takes place above that site. Other locations must be sampled to get production estimates of other runs. Trawl sampling replaces screw trapping in the tidal reaches of the estuary, particularly near Sacramento, Mossdale, and Chipps Island. Trawls collect fish without regard to their rate or direction of movement.

Most monitoring is less robust than that at RBDM and is focused primarily on determining timing of movement and size distributions of the fish. These efforts could be upgraded to determine fish flux, or the number of young fish passing a selected location per day. Trawls were designed to determine relative abundance, timing, and size distributions of salmon but they could be converted to fish per unit volume if the net efficiency for the species and size class can be determined. To determine fish flux the fish per volume estimate is multiplied by the cross-sectional area of the channel in the depth range over which the fish are found, and their speed of movement. Ideally this should be determined by mark-recapture studies, although net (river-derived) velocity could be used until such studies are completed. .

Survival estimates: With estimates of fish flux, survival between the sampling points can be determined simply as the ratio of fish flux at one location to that at an upstream location. Because errors are likely in the calibration at each location these estimates might be most useful as indices for statistical analysis of potential causes of interannual variability or trends.

Extending the use of the data to estimate fish flux involves several assumptions and calculations of net efficiency. These add uncertainties that some fishery scientists may object to. But to understand and track the impacts of management actions (including re-plumbing the Delta and restoration) and likely long-term trends (e.g., changing ocean conditions, increasing temperature, declining snowpack, changes to the physical configuration of the Delta) requires a general understanding of the role of each component of the migration corridor in survival: information beyond survival of fish over various life stages or regions, losses of fish to export pumping, and the numbers of fish leaving the estuary. Fish flux estimates at Red Bluff for winter Chinook are reasonably close to estimates of production of young fish based on carcass surveys and fecundity estimates. Thus if it feasible to develop this approach as an indicator with relatively low uncertainties,.

Modest efforts at some locations have been focused primarily on determining timing of movement and size distributions of the fish. These also could be upgraded to determine fish flux, which would be valuable information for selected locations. Brown (unpublished) noted that releases of tagged fall run each year at various locations could also be used as an annual estimate of changes in survival through the system – eg releases of smolts in the Feather River, in the Sacramento River near Sacramento and below the Delta. Advances in acoustic tagging or pattern recognition could improve some of the uncertainties in the more traditional approaches that have limited the interpretation of such data.

Run and Reach Contributions and Access to the Bay

As noted above, each tributary contributes differently to anadromous salmonid populations. Measuring the cumulative abundance of migratory salmonids entering and leaving each tributary provide the basic indicators of overall salmonid status in the major migratory corridors. It can also be used as a measure of performance in achievement of targets. Abundance measurements within each tributary include counts at the Red Bluff Diversion Dam, carcass surveys, and redd surveys, as noted above. Improvements in consistency and documentation of methodologies could allow evaluation of the different tributary influences on migration to the Delta and addressing the overall importance of changes or restoration in specific tributaries.   Brown also called for an ongoing inter-basin comparisons of the Sacramento and San Joaquin rivers. These streams appear to behave somewhat differently – perhaps in part due to the large number of hatchery fish coming out of the Sacramento basin. The San Joaquin basin emigrants have more direct exposure to stressors in the South Delta; a more disturbed water quality, and lower flows and warmer temperatures during the fall run emigration period.   At present, Fall run on the San Joaquin system seem to have fewer adults returning per unit flow in their stream rearing period – ie the runs still respond to stream flow but not to the extent they did in the past. But substantial restoration efforts are being proposed for the San Joaquin and some dramatic changes in development of water projects are being proposed.

Environmental attributes can also be employed as a surrogate to evaluate the success of salmonid migration to the Bay and on to the ocean. There is a strong historic relationship between San Joaquin River flows and outmigration of Fall run salmonids from that river. The Biological Opinions call for monitoring this indicator so data will be readily available. The ratio of SJR flows to exports is more controversial in terms of links to salmon outmigration; but it should also be included in the regular reporting of trends in UMARP. More specifically, it might be more precise to determine for each year if there is a 10 day window for outmigration to occur, when SJR river flows are greater than one-third of exports. Brown proposed that the relation between stream flow and escapement 2.5 years later also might be a good indicator for fall run in this river, although less analysis of the metric is available. This relation has some historical context and seems to be changing. It is proposed that the second phase of UMARP development use the San Joaquin River basin as a case study in a next step for the program. Access from the Sacramento River to the sea is also thought to be impeded when Old and Middle River flows are strongly negative and this should also be included in the interpretation of salmonid migration.

What. Relative contribution of different tributaries to migration corridor. Access from major migration corridors to the sea.
Why. Evaluate influences of environmental changes in specific contributors to the migration.
How. Use in a cumulative calculation data from each tributary, as described in earlier sections. This will require improved consistency and documentation of methodologies employed in each tributary. Use environmental flows as indicators of the potential success from the river mouths to the Bay.

Delta as a Nursery

Beach seine surveys and rotary trap monitoring indicate that many salmon leave natal streams as fry, some immediately upon emerging from the gravel. Many of them rear in the Delta for up to several months. The contribution of these fish to ocean recruits is unknown, and therefore the importance of protecting them in the Delta is unknown. Thus it is essential to determine the contribution of these fish to ocean populations, relative to that of fish that emerge from the river as smolts and go to sea over a relatively short period. If Delta rearing contributes substantially to ocean populations, the current management emphasis on fish that rear in the rivers will need to be reconsidered. Comparing numbers of fish at Mossdale to fish passing Chipps Island from year-to-year may provide some indication of changes in Delta rearing. Ultimately a monitoring program for Delta rearing should entail expanding research tools, such as acoustic tagging, to an annual experiment for monitoring purposes. Some uncertainties are involved with using hatchery-reared surrogates in such studies, but with advances tools like acoustic tags enough of them can be marked to be useful. It also seems feasible from research studies to employ ring analysis and microchemistry on otoliths to distinguish fish that rear in rivers from those that rear in the Delta and to evaluate differences in growth rate. Understanding changes in the rearing function of the Delta may be an especially important indicator of change if some of the proposed changes in Delta infrastructure are implemented.

Ocean conditions

It is extremely likely that ocean conditions are one of the drivers of salmonid populations. It is well known that changes in the Pacific Decadal Oscillation (PDO) are linked to fluctuations in salmonid populations in the Northwestern US. Such links may be more complex off California, but are nevertheless likely to be influential. Recent studies (Cloern, 2010) show the broader links between ocean conditions (including the North Pacific Gyre Oscillation or NPGO) and ecosystem structure and function (including fish populations) in San Francisco Bay and Delta, as well. Thus data on these ocean conditions should be part of the UMARP comprehensive assessment and reporting. In particular, systematic consideration of available data as simple as an index of upwelling or conditions related to ENSO events, the Pacific Decadal Oscillation or the NPGO would take advantage of existing programs. Systematic and regular consideration of these data must be part of UMARP's comprehensive assessment and reporting on anadromous salmonids.

What. Broad ocean condtions like upwelling, ENSO cycles, PDO and NPGO.
Why. These are likely to be first order drivers of salmonid populations.
How. Take advantage of existing data and programs. Assess and report as part of developing a comprehensive assessment of trends in drivers across the tributaries, migration corridors, the Delta, the Bay and the oceans.

Rivers, Delta and the Sea: Exogenous Environmental Attributes Important to Anadromous Salmonids

Monitoring indicators of salmonid populations alone is insufficient to explain why changes are occurring. We have learned from past experience that trends themselves are very unsatisfying to policy makers; monitoring must include exogenous indicators that track the potential drivers of trends. An ongoing and systematic assessment of key environmental drivers, which we will term important exogenous environmental attributes, can point toward the most effective directions to pursue in explaining trends in populations of anadromous salmonids (Table 4).

Table 4. UMARP monitoring of exogenous environmental attributes influential in determining salmonid populations in the migration corridors, the Delta and the Bay.

Purpose	***Assessment: Indicators***	***Evaluation: Metrics***	***Monitoring: Measurments***	***Feasability***
Hatcheries	Percentage wild fish in ocean catch compared to hatchery fish	a. Population hatchery fish. b. Population of wild fish. Ratio: b/a.	Coded wire tag in: a. ocean fishery[6]. b.. Genetics on samples from salvage, trap/trawl	1
Genetic impacts of management practices	Genetic baseline for each major run.	a. Number of fish in each race identified by genetics. b. genetics of hatchery vs. wild fish	Genetics on trawl captured or screw-trapped fish: Sampling design needed	3
Exports: Direct	Take at Delta facilities	Take at export facilities/Juvenile production	a.Salvage[7] b. Carcass survey for production c. Fecundity estimates based on size (JPE).	1
Exports: Indirect	Zone of influence of facilities during times juvenile salmon are present in Delta.	a.Various averages (daily, 5-day, 14-day, seasonal) of OMR flows. b. daily export flow. c. Daily Vernalis, Stockton DWSC, and QWEST flows. d. Delta Transfer Flow. e. Averaged flows through entrance gates of CCFB. f. Delta gate and barrier positions. g. Outmigrating smolt route selection and reach-specific losses as a function of flow and exports.. h. Vernalis Flow: export ratio during spring	a. Tidal (15-min) flows in Old and Middle Rivers. b. Hourly pumping rates (CVP and SWP). c. Tidal flows in San Joaquin River (at Vernalis, Stockton, and Jersey Pt). d. DCC and Georgiana Sl. flows. e. Tidal flows through entrance channel to CCFB. f. Delta gate and barrier operations and culvert flows (DCC and HORB especially). g. Acoustic tagging studies.	1
Delta habitat	Suitable delta habitat	a. Monthly average flows, turbidity and temperature, when and where salmon are in Delta….Metric is monthly average (Apr-Jun) b. Carbon exports and carbon balances. c. Macrophyte habitat	**** Network: temperature; salinity, turbidity, instantaneous flows (IF), suspended sediments, TOC, chlorophyll, nutrients including ammonia, oxygen at most North Delta	a., b., c., d.: 1 e.:3

		area. d. Phytoplankton including *Microcystis* e. Salmon counts in specific habitats.[8]	sites on 15 minute time interval. at: Sutter, Cache slough, Steamboat, Freeport, below Freeport, Delta Cross Channel dates or PC, Georgiana slough flows.	
Predation	Predation	Index predator abundance	Counts of predators (when and where?).	3
Contaminants	Salmon health indicators specific to contaminants	Proportion of individual juveniles expressing a.reduced condition index of juveniles b. biomarker responses indicative of endocrine disruption	a. length and weight from collections b. Vitellogenin analyses in males c. acetylcholine-esterase analysis	2
Impact of harvest	Ocean harvest	a. harvest vs. abundance (% population). b. annual allowable harvest c.Predicted population size at year +1.	a. Commercial harvest. b. Party boat catch data. c. Total salmon production d. Expected ESA escapement	1

[1]See tributaries matrix for more detail on upstream, stream-by-stream monitoring.
[2] Expand survival studies to North Delta to understand Peripheral Canal.
[3] Survival from spawning and through the Delta. How many fish come out of system compared to how many produced.
[5]Experimental. Will require development and validation of monitoring methodology.[6]Improved estimates will require mass marking of all hatchery-reared fish using some combination of thermal marks, dye, and coded wire tags. Proportional marking is an increasingly insensitive indicator of % wild fish wild population because such a high percentage of salmon are of hatchery origin.
[7]Conversion of salvage to take requires some correction factors for various influences. Magnitude of those factors is large and very uncertain.
[8]Develop models (based on correlations) predicting when and where migrating salmon occupy the Delta and compare those to observations; then define how that comparison changes over time?

Hatchery impacts

As noted a continually increasing supplementation of natural populations with hatchery fish could have a long-term impact on the sustainability of salmonid populations. The National Resource Council (NRC 1996) identified demographic risks as well as genetic and evolutionary risks as the percentage of hatchery fish in a population grows. Hatchery fish can also differ from the natural population in behavior, health, physiology and functional ecology (Williams, 2006). Williams quoted a panel of experts: “Inevitably, hatchery brood stock show domestication effects and genetic adaptations to hatchery environments that are generally maladaptive in the wild.”

Coded wire tags are presently employed to determine the proportion of hatchery fish in ocean landings. Combined with estimates of total population abundance, the percentage of hatchery fish is an obvious indicator of the level of risk from hatchery supplementation. This is another instance where uncertainties in the estimates derive from the small and in consistent proportion of fish that are tagged (for fall run). Tagging all fish, or use of new methodologies for identifying hatchery fish could greatly strengthen this indicator.

Feasible future indicator: genetic monitoring. Genetic change is perhaps the most serious of the effects of hatcheries because such effects could persist even if hatchery production is ended. Systematic and consistent monitoring of genetic characteristics could be an indicator that directly addresses one of the most important risks from hatcheries. Fish are already being collected during salvage at the diversion points. From these fish, tissue samples could continue to be collected and archived. The first goal might be to develop a genetic baseline for fall run salmonids and their hatchery cousins; then begin to monitor genetic impacts of management practices. It might be adequate to collect and archive the samples and do the genetic typing every few years as better analytical techniques are developed.

What. Assess proportion of hatchery fish in total populations of fall run and winter run Chinook salmon.
Why. Indicator of myriad risks from supplementation of natural population with hatchery raised fish.
Target. Increase the percentage of natural fish in fall and winter run populations over time.
How. At present use coded wire tag counts in ocean catch. In future include genetic analysis, otoliths or other advanced tools. Increase percentage of tagged fish in future (mark all hatchery fish).

Direct impacts of the export pumps

Pre-screen mortality and entrainment of salmon at the water export facilities is a source of mortality and as a readily measurable metric, has long been of concern to Delta managers. Take at the export facilities is an index of losses (although it is probably not tightly proportional to losses, see Kimmerer 2008) and therefore a useful and traditional indicator of this potential stressor. The appropriate metric is weighted for the size of the population: the proportion of the population lost to this source of morality. The calculation is total take for the season divided by the juvenile production estimate (JPE). This requires information on take, adult escapement by age, egg production by age and alternative measures of juvenile production when available. At present the management target is 2% of the JPE for winter Chinook; no targets are set for other salmonids, as take limits apply only to listed species/races. This target was employed to regulate exports by the Environmental Water Account.

Uncertainties. The proportional measure assumes that the per capita reproductive rate and early survival of juveniles are constant. As of 2006 the former appeared relatively constant based on the JPI derived from RBDD screw-trap counts. The proportionality is

also sensitive to variations in loss rate to predation and other causes of mortality before the fish arrive at the screens. These are unlikely to be constant.
Take is estimated total salvage for each day, and seasonal take is the sum of daily take during that season. Adult abundance is determined from carcass surveys taken during the spawning season which give estimates of abundance (with confidence limits) by age determined from scales. Fixed values of fecundity by age, previously determined in hatcheries, and a constant 1:1 sex ratio are applied to get egg production. A fixed estimate of survival from egg to migrating alevin or smolt is then used to estimate juvenile production.

Monitoring using this data is most feasible and least uncertain for take by size class and for steelhead, although actual mortality depends on unknown pre-screen mortality. Take by run of Chinook salmon is less certain because of uncertainties in the link between size and run. Uncertainties are small in the JPI based on RBDD screw-trap counts for winter Chinook. But the JPI is more uncertain for other runs because adult abundance is less certain. Nevertheless, this indicator will be especially important to monitor, assess and report on if infrastructure changes in the Delta (Will loses to exports decline as expected? Grand Challenge 1).

Why: Source of salmonid mortality. Strong management interest.
What: Proportion of population suffering take at the export facilities.
Target: 2% of JPE.
How: Use existing estimates of take and JPE from tributary monitoring.

Indirect effects of export pumps
In addition to causing direct mortality by entrainment, exports alter hydrodynamic conditions and salmon migration cues in the Delta. These lead to indirect mortality, by increasing exposure to predator fish or by potentially prolonging exposure to contaminants, high temperatures or other adverse water quality conditions. Creation of reverse flows within central and south Delta channels can also reduce primary and secondary productivity due to export of the carbon that forms the food web base. This may affect the rearing qualities of the Delta by reducing the forage base for juvenile salmonids. Over the longer term, large-scale exports of water have also created a stabilized freshwater ecosystem in the Delta that has altered ecological characteristics to a degree that may have increased the potential for predation of outmigrating juvenile salmonids.

The most effective indicator for these indirect effects is the zone of Influence (ZOI) of facilities. Here, we use the term "Zone of Influence" to describe the region of the Delta in which hydrodynamic transport is measurably influenced by export pumping. The ZOI is distinguished from the "Zone of Entrainment (ZOE)," which describes a different, smaller region wherein at least some fraction of the water or warterborne particles at each location within the region are transported and entrained to the export facilities. The defining of these zones is central to understanding and quantifying the influence of export pumping on hydrodynamic transport of fishes in the delta, and for the understanding of both direct and indirect mortality. These zones can only be estimated by particle-tracking models and not by direct measurements in the field. The metrics that are needed to determine the ZOI include (a) Various averages (daily, 5-day, 14-day, seasonal) of OMR flows, (b) daily exports, (c) daily Vernalis flows, daily flows through Stockton DWSC, QWEST, (d) Delta Transfer Flow, (e) daily flows through entrance gates to CCFB, (f) delta gate and barrier positions (especially DCC and HORB). These are derived from (a) 15-minute tidal flows in Old and Middle Rivers, (b) hourly pumping rates (CVP and SWP), (c) 15-minute tidal flows on the San Joaquin River (at Vernalis, Stockton, and Jersey Pt), (d) DCC and Georgiana Slough flows, (e) CCFB entrance flows, (f) delta gate and barrier operations and culvert flows (especially DCC and HORB). A larger ZOI from the pumps is thought to increase indirect mortality, but this also depends on the presence of fish in the ZOI. Quantifying this stressor therefore has to be linked to fish monitoring also (such as Mossdale and Sacramento trawls). Tracking this indicator as infrastructure and water management change in the Delta will be key to understanding how regulations and new facilities are performing (Grand Challenge 1).

Feasible future indicators. In the long term, annual acoustic tagging studies might be used to determine route selection and reach specific losses as a function of flows and exports for outmigrating smolts.

What. Changes in the Zone of Influence of the export facilities from year to year. For outmigrating SJR salmonids (fall-run salmon and steelhead) during spring indirect losses are thought to be much larger than direct losses, but quantification has been difficult
Why. A larger zone of influence is thought to be a source of salmonid mortality. Potential direct causes are identified but the importance of each has been difficult to quantitatively characterize.
Target: No endogenous salmonid target has been identified because the magnitude of indirect mortality is mostly unknown. But an exogenous physical target based upon direction of OMR flows has been proposed.
How: Incorporate various physical measures into a particle tracking model to calculate ZOI along the routes where (and when) juvenile salmonids are present. Acoustic tracking studies could identify routes of salmonid migration and how they change year-to-year to supplement the assessment.

Delta Habitat

The capability exists to establish a long-term water quality/flow surveillance network for Delta waters. The simplest metrics to track through time are the basic characteristics of Delta habitat: turbidity, temperature, salinities, hydrodynamic characteristics are critical locations. Trends in these general characteristics of water quality will be a consideration when putting together the salmonid story for the Delta. All four Grand Challenges could result in changes in water quality characteristics of the Delta, with implications for many species. Many such changes could be very rapid (e.g. Monsen and Cloern, 2008), giving immediate feedback about implications of some actions or environmental changes.

More complex metrics are also feasible. For example one metrics of particular interest to salmonids might be trends in carbon exports from the Delta and determination of carbon mass balances, given the links between carbon and the nursery function of the Delta. Macrophyte habitat area is another habitat characteristic with potential links to salmonid populations via creation of habitat for predators of salmonids.

Feasible future indicator. The greatest value of this data from the network might be to build simple models from relationships with network variables and spatial/temporal population indices, to characterize and track through time habitats of various fish species in the Delta, including salmonids.

What: Trends in hydrologic and biogeochemical characteristics of Delta waters (water quality).
Why. Rapid (days to months) physical and chemical responses to human actions or environmental change can provide early warnings of longer term biological implications.
How, where, when. A real time hydrologic network is a feasible reality for the Delta. Much of it is in place, although long-term institutional commitments are not yet guaranteed. Time and space scales for data interpretation should be metric-specific.

Predation

As noted above, predation in the rivers and Delta probably causes substantial mortality to salmonids both during migration and residence (Lindley and Mohr 2003). This source of mortality has been difficult to quantify. Nevertheless, monthly and annual abundance indices of key predators like striped bass, largemouth bass, and pikeminnow would provide a first order estimate of how this potential source of mortality is changing. Striped bass can be determined from catch per trawl in fall MWT and Bay Study trawls. Catch per trawl in the two surveys is determined from numerous samples taken monthly all year (Bay study) or in fall (Fall MWT). Annual catch per unit effort would be the appropriate metric. Largemouth bass populations are more difficult to quantify (see later discussion of this IEA), although electrofishing is not now done quantitatively.

Uncertainties. Variation in predator abundance likely corresponds to variation in predatory loss rate, but the shape of the relationship is unknown for all predators. Nevertheless, raw predator abundance data may be useful in long-term correlative analyses; for example, if predators are increasing over a time period in which salmonid survival or production is decreasing. Tracking this data would be a “best available” indicator for a possible salmonid (and other fish) stressor and would be relevant to all Grand Challenges, despite the uncertainties of the connection to population abundances. Estimates of predation rate would be needed for better establishing a causal link or for using shorter-term data in a less aggregated analysis.

What. Predator populations: striped bass, large-mouth bass.
Why. A broad indicator of trends in a potentially important source of mortality.
Target. None
How. Data per trawl from MWT and Bay surveys, as well as quantitative electrofishing.

Contaminants

“Contaminants” is a broad term, characterizing a diverse suite of chemicals, many of which could be toxic to species of concern in the Delta (see also the surveillance network discussion). Contaminants are a potential stressor for salmonids, but again one whose implications are poorly quantified. The contaminants of special concern to salmonids might include bioaccumulative organic chemicals and mercury, because salmonids are top predators. Salmonids are also especially sensitive to selenium, although they are not exposed to concentrations as high as those experienced by fish and birds that feed on bivalves. Poor survival in *ad hoc* studies of juvenile salmonids caged in the Delta also indicate sources of immediate toxicity could be important (e.g. pesticides).

Future feasible indicator. Because of the diversity of potential stressors an integrative suite of quantitative metrics, termed biomarkers, could be a valuable indicator of contaminant stress. Because of the feasibility of collecting out-migrating juvenile salmonids, biomarkers could assess stresses specific to salmonids. Biomarkers are sub-lethal, physiological, histopathological and biochemical responses to contaminant exposure often employed in monitoring programs (Anderson et al, 2007, *BIOMARKERS AND THE PELAGIC ORGANISM DECLINE*). Sublethal responses to contaminants are not necessarily strong evidence for effects at the population level, but are early warning signs that such responses are possible. Because a goal of UMARP is to obtain early signs of environmental change, sublethal responses are appropriate for this monitoring program. Biomarkers could be determined in juvenile salmonids collected in the IEP surveys or at the diversion facilities. A large enough number of samples must be analyzed to express the metric as proportion of population affected.

Examples of biomakers include lipid peroxidation typical of responses to metals; acetylcholinesterase inhibition; or vitellogenin in male fish, which are responses to endocrine disrupting chemicals like some pesticides; P450’s which is a response to organic chemicals found in urban runoff; or biomarkers of oxidative stress which is a typical general stress response. Fish condition is also a broadly useful metric that can be used as a link to aspects of individual health such as reproduction, growth, and energetic. The goal would not be to determine if biomarker responses are occurring but to evaluate long term trends in biomarker prevalence and in condition indices.

One important caveat in the use of these biomarkers is the importance of establishing a baseline of responses typical of unstressed populations. No such baseline exists for the Bay-Delta. Long-term data sets do not exist for any of these measures for salmonids. Therefore a new monitoring scheme for this indicator will be necessary. Until such an effort is initiated, contaminant monitoring will continue to be dependent upon measured concentrations of individual chemicals in the environment, which are neither species specific nor unambiguous to interpret with regard to implications for salmonids.

What. The proporition of individual (juvenile salmonids) expressing indicators of stress that might derive from exposure to contaminants.
Why. An indicator of net outcome of stress resulting from exposure to multiple types of contamination.

Target. None set
How. Systematically collect and analyze out-migrating juvenile salmonids from export facilities and IEP surveys for analysis. No historical data.

Ocean harvest

The importance of physical ocean conditions was noted above. Salmon harvest is also a type of ocean-based stressor that is important in determining how many salmon can return to their native streams. The metrics and variables involved in calculating harvest are shown in Table 4. Estimates of ocean harvest (including estimates of the total fraction of the potential escapement that is harvested in the ocean), harvest effort and salmonid age structure are available from the sampling effort related to recovering tags in the ocean fisheries. All four Grand Challenges could potentially affect anadromous salmonid populations, and any analysis of such populations must consider trends in ocean harvest. Therefore this indicator is applicable to all Grand Challenges.

What: Trends in ocean harvest of anadromous salmonids
Why. An important influence on how many salmonids return to their native breeding grounds.
How. Data available from regulatory agencies.

Native, mobile, pelagic fishes in the Delta

Delta Smelt

Delta smelt is the most important fish in the estuary from the perspective of management. As an annual fish that spends much of its life in the freshwater Delta, it is particularly vulnerable to catastrophic mortality and to habitat degradation in the Delta. It is in a severe state of decline. Neither one specific or overwhelmingly dominant reason for the decline has been identified, nor have ways to reverse it become clear. Multiple factors are likely to involved in the well being of Delta smelt, therefore all life stages and all of its habitat are of interest for monitoring (Table 5).

Table 5. Important environmental attributes in a unified monitoring, assessment and reporting for Delta smelt.

Purpose	ASSESSMENT	EVALUATION	MONITORING	FEASIBILITY
Population size	INDICATORS Abundance index	METRICS Annual population index	VARIABLES FMWT catch/trawl	1
Population size	Index of abundance by region and date ; location and seasonal movement.	Catch per unit effort by region and date.	All surveys	1

Life cycle	Larval, juvenile and adult condition in each season and in different regions	Health metric: Growth, condition, indices of stress, trophic level	*Length, weight, age and growth rate, condition, biomarkers, isotope ratios, genomic information, and feeding for fish captured by all programs	1
Life cycle	Adult Reproductive condition	Distribution, Fecundity, Intersex.	Spring Kodiak trawl	1
Habitat	Amount and location of habitat by season/life stage	Habitat area or index	Catch per trawl, salinity, turbidity, temperature from all surveys, and continuous monitoring data.	1
Habitat	Food	Abundance of copepods , mysids	Zooplankton abundance by species	1
Losses at export facilities	When are delta smelt at risk	First date of adult salvage	First presence of adults in salvage	1
Losses at export facilities	Index of direct mortality of adults	Adult salvage divided by previous fall midwater trawl catch/trawl	Salvage at federal and state facilities	1
Losses at export facilities	Estimate of direct mortality of larvae	Larval catch /trawl in S. Delta X OMR flow related to total abundance	Catch per trawl in larval survey by station, OMR flow	2
Losses at export facilities	Risk of entrainment	Tidally averaged OMR flows; average turbidity in south Delta in winter	Old River flow Middle River flow Turbidity in South Delta	1
Eggs	Egg production index	Eggs deposited	Egg surveys to be developed	4

Indicator: Abundance index

The size and health of the Delta smelt population is estimated using indices based upon samplings at different stages in the life cycle. One of the two most important abundance metrics to track over time is the annual population index. The Fall Midwater Trawl (FMWT) program provides the annual abundance index used to track population trends in delta smelt. The index is calculated from catch per trawl of fish in ~100 samples during September – December. Recent studies suggest a better metric might be Catch per Unit Effort or Catch per Tow (Noriga, official memo). In any case the measurements from which the abundance estimate is derived are the same.

The second is the data on catch per unit effort for each major region and life stage. Geographic distribution by season and life stage can help assess vulnerability of population at different phases in its life cycle and explain trends in abundance index. Movement patterns are inferred from this data. Different sampling programs collect delta smelt at different stages in their life cycle. Data from each can be used to develop indices of abundance in different seasons to complement the FMWT index. These include the San Francisco Bay Study, spring Kodiak trawl survey (adults), spring 20mm survey (late larvae and juveniles), spring larval survey, and summer townet survey. The Bay Study samples throughout the year but does not sample much of the Delta. Mean catch per trawl (catch per unit effort) should be used either by survey or averaged across selected surveys, and either for regions or for the entire geographic extent of the survey. Data on Delta smelt populations are relevant to all Grand Challenges.

What. Track trends in the population based on fall abundance index and distributions when different stages of the life cycle are dominant.
Why. Direct measures of population status at each life stage.
Target. Abundance targest are set by Delta Native Fishes Recovery Plan. No target exist for distribution or for life stages other than adults.
How. Data available from existing surveys.

Indicator: Condition of individual fish

Changes in the condition of individual fish, and the proportion of the fish captured with different condition status, can aid understanding of changing population trends, causes of impairment or poor success of a given year class of fish (Bennett, 2006). Research shows that a number of measurements that reflect the health status of Delta smelt are feasible.

Feasible future indicator. As a part of UMARP, all sampling programs in which delta smelt are collected should determine several measures of the condition of the captured fish. The goal is to obtain the most information possible out of each individual fish. Reproductive condition of individuals is presently available on a regular basis (from the spring Kodiak Trawl).

Feasible future indicators. In order of effort the following new metrics also could feasibly be determined on a regular basis:

a) Length and weight of each individual fish would provide an index of overall physiological condition.
b) Otolith measurements are also feasible, to provide information on length-at-age, growth rate, and natal origin.
c) Histopathology or other methods have been used to assess the degree of toxic impairment or starvation;
d) gut contents, genetic analysis and stable isotope analyses are feasible to assess feeding and determine prey composition (note: this requires parallel samples for meso- or macrozooplankton).
e) Adult reproductive condition is useful as supplementary information for assessing population trends, and for determining the timing and general location of spawning.

Employing this suite of methods will require careful coordination and preparation because preservation methods differ for the various measurements. But taking maximum advantage of the individuals that are captured in the various sampling programs makes sense, and, if systematically developed, could provide a database of immense explanatory value.

What. Multiple indicators of fish condition.
Why. Understand factors underlying population trends; help distinguish among causes of impairment or poor success of a given year class of fish
Target None
How. Different life stages of Delta smelt are available from the surveys in different seasons and from take at the export facilities. Methods have been demonstrated in research studies but only adult reproductive condition is regularly reporting in existing monitoring programs.

Indicator: Habitat

The extent of suitable habitat available for Delta smelt is affected by the ways that water is managed in the Bay-Delta, as well as by climate and other exogenous factors. Changes in the extent and quality of habitat are possible drivers of the downward trends in the abundance of the species. Delta smelt are pelagic fish and the appropriate habitat for each life stage can be defined by water within a certain range of characteristics including salinity, turbidity, depth, and temperature; food in the form of native zooplankton; and inflows to the Delta. These habitat characteristics interact and change with season. Their influences appear to change with life stage in complex ways. Detecting changes in some of these attributes has helped explain at least aspects of the long-term patterns of abundance (e.g., Feyrer et al. 2007). From the monitoring point of view, a surveillance network is essential to collect the basic data described above on a sufficient temporal scale and a sufficient spatial scale to interpret the different surveys of Delta smelt.

Metrics are necessary to constrain the above data in meaningful ways. Informative statistical relationships have come from correlations between individual variables and indices of Delta smelt abundance such as catch per trawl. Relationships among habitat variables can also be useful. For example, a statistically significant relationship has been shown between X2 and the combination of salinity and turbidity. In this indirect way, X2 influences smelt habitat, even if it does not correlate itself with smelt abundance (Feyer et al 2007). Simple models, such as the salinity + turbidity habitat model that describes habitat area, seem to be more informative than the single factor correlations for Delta smelt. In another example, temporal trends in a model index that includes X2 normalized for flow, suspended sediment and a measure of native food availability (mysid populations) captures some aspects of the temporal patterns in smelt abundance (Nobriga and Cholodenko, 2010, internal memo). At this point, no single metric necessarily can explain trends in Delta smelt, but an ongoing analysis of metrics like these are possible as long the appropriate surveillance data are in place. For a complex situation like Delta smelt, UMARP can provide ongoing assessment of different models, supported by the appropriate surveillance monitoring.

Feasible future metric. Food is also an important attribute of habitat and there have been indications of potential food limitation of Delta smelt in recent years (Feyrer et al. 2003). Food of delta smelt is comprised of copepods during early life, and some mysids for adults. The IEP zooplankton monitoring program tracks abundance of these organisms through the Delta and Suisun Bay. In the index described above, mysid abundance was incorporated with physical data to develop an index. A separate metric also could be developed to track changes in food abundance itself. That metric might be more realistic if zooplankton samples were taken in conjunction with the fish sampling to provide a more immediate picture of the prey field where the fish are. Such data are also important if fish diets are to be examined through gut content analysis. Metrics that would help characterize trends in relative abundances of key (probably native) zooplankaton species and relative abundances of the most problematic of the invasive species might simplify interpretation of the monitoring.

What. Metrics that define the extent and character of the physical and biological habitat of Delta smelt.
Why. Area, location and quality of habitat are likely to be linked to the well being of Delta smelt.
Target. None
How. Link physical and biological determinations with Delta smelt sampling and use statistical relationships and models to define extent and quality of habitat as well as abundance of food.

Indicator: Impact of the export facilities.

Losses of delta smelt to the export facilities may comprise substantial mortality in some years. Regulatory changes in export operations are the result of such losses. Both direct measures of the number of fish taken at the facilities and physical measures in the environment should be monitored in UMARP to track these changes. Salvage at export facilities in ~mid-December increases when the adults move into the freshwater Delta. Trends in the timing of first arrival at the export facility may be an indicator of trends in the timing of migration. But from that time until late spring when juveniles leave freshwater, some life stage is vulnerable to export losses. One important metric to track through time is the entrainment of adults at the export facilities. Salvage at export facilities can be related to mean catch per trawl in the previous November-December fall midwater trawl survey (Kimmerer 2008). Direct mortality of larvae at the export facility can also be determined. Catch per trawl as determined in larval surveys begun in 2009 and could provide a context for such data. Losses can be determined as in Kimmerer (2008). All entrainment salvage numbers are subject to uncertainties, especially in their correction factors. Salvage also may be affected by population size. Consideration of such factors is essential in interpreting the data and the trends.

Because of the challenges in determining direct mortalities at the facilities, physical measurements can also be employed to provide a measure of the risk of entrainment of adults at export facilities. Relationships between entrainment of Delta smelt and the directional flows of Old and Middle River are well known, although thresholds for effects are somewhat controversial. Monitoring and assessment could focus on metrics such as the amount of time OMR flows are below pre-established values chosen to represent thresholds in December – March. Similarly, turbidity influences the presence of Delta smelt in the Zone of Influence of the facilities. At present turbidity is measured at 3 stations and averaged. Changes in average turbidity in Dec. – Mar; or the percentage of time that average turbidity is above or below a certain value would be useful metrics and could be derived from existing data.

What. Metrics defining impacts of export facilities or risk from such impacts: Entrainment or salvage at facilities, OMR flows, turbidity in zone of influence.
Why. Losses of adults and larvae to the export facilities may comprise substantial mortality in some years.
Target. No target proportional to population; biological opinions set some targets.
How. Entrainment, salvage, OMR flows, and turbidity data are all being collected but are reported only on an *ad hoc* basis in the context of other Delta smelt indicators.

Indicator: Egg abundance and distribution
Future indicator: Not feasible at present. Estimates of reproductive output (e.g., surveys of pelagic or demersal eggs, salmon redds) are among the most effective and efficient methods to determine the size of spawning stocks. Ultimately this approach could be quite effective in reducing uncertainties about the status of Delta smelt, and thus it deserves mention here. However, eggs have not yet been found and methods do not exist to routinely find and survey egg abundance and distribution. In the near term this indicator is not suitable for UMARP, but with the development of reliable understanding and methods it could be invaluable.

Longfin Smelt

Longfin smelt offer an interesting contrast to delta smelt in life history and habitat. Both spawn in fresh to brackish water and rear in saltier water. Both are essentially planktivores but longfin smelt switch to mysids and amphipods after their first summer. Longfin smelt spawn at age 2 rather than primarily at age 1, and occur far seaward of the distribution of delta smelt, in San Pablo to Central Bay and even into the coastal ocean (Rosenfield and Baxter 2007).

Table 6. Important environmental attributes in a unified monitoring, assessment and reporting for lonfin smelt.

Longfin smelt	ASSESSMENT	EVALUATION	MONITORING	FEASIBILITY
Population size	INDICATORS Abundance index in relation to flow	METRICS Annual population in relation to X2 or log of Delta outflow	VARIABLES FMWT mean catch/trawl	1
Population size	Index of abundance by region and date ; location and seasonal movement.	Catch per unit effort by region and date.	Larval survey, FMWT, Bay Study midwater and otter trawls	1
Life cycle	Larval, juvenile and adult condition in different seasons and regions	Health metric: Growth, condition, indices of stress, trophic level	*Length, weight, age and growth rate, condition, biomarkers, isotope ratios, genomic information, and feeding for fish captured by all programs	2
Life cycle	Adult Reproductive condition	Distribution, Fecundity, Intersex.	Spring Kodiak trawl	2
Habitat	Amount and location of habitat by season/life stage	Habitat area or index	Catch per trawl, salinity, turbidity, temperature from selected surveys, and continuous monitoring data.	2
Habitat	Food	Abundance of copepods ,	Zooplankton abundance by	2

		mysids, amphipods	species	
Losses at export facilities	Index of direct mortality of adults	Adult salvage divided by previous fall midwater trawl catch/trawl	Salvage at federal and state facilities	2
Losses at export facilities	Estimate of direct mortality of larvae	Larval catch /trawl in S. Delta X OMR flow related to total abundance	Catch per trawl in larval survey by station, OMR flow	2
Eggs	Egg production index	Eggs deposited	Egg surveys to be developed	4

The justification for the indicators and metrics and the choice of data is much the same as for Delta smelt. A key difference is that abundance of longfin smelt responds the most strongly of any species to freshwater flow from the Delta , whereas delta smelt has no detectable quantitative response to freshwater flow. This means that annual abundance indices should be scaled to expected values based on flow. The Fall Midwater Trawl (FMWT) program provides the abundance index used to track population trends in longfin smelt. The index is calculated from catch per trawl of fish in ~100 samples during September – December. Since this index is strongly related to freshwater flow, this relationship should be used to distinguish trends in abundance from effects of flow.

It is also important to track trends in geographic distribution by season/life stage, using a metric from each of the different seasonal sampling programs to track each life stage from year-to-year. The Bay Study also collects longfin smelt but samples throughout the year and includes more of the longfin smelt's saline habitat. In addition the otter trawl is more effective than the midwater trawl at collecting longfin smelt, which are more abundant near the bottom when in high salinity. This provides supplementary information on abundance patterns. Additional information may be available from the spring 20mm survey and larval survey.

Condition of individual fish should be tracked over time in UMARP, as with Delta smelt. This applies to all sampling programs in which longfin smelt are collected. Individual fish collected in all sampling programs can be retained for the same measurements described above for Delta smelt. Although the reproductive condition of longfin smelt is not regularly monitored at present, the spring Kodiak Trawl targets delta smelt but catches some longfin smelt. If it is feasible the reproductive condition of these fish could be determined as for delta smelt.

In tracking the physical habitat of longfin smelt, the metrics used to determine habitat area for Delta smelt should be of value. Food of longfin smelt is comprised of copepods during early life, then mysids and amphipods after about the first summer. The IEP zooplankton monitoring program tracks abundance of these organisms through the Delta and Suisun Bay, but samples at only one station in San Pablo Bay and not at all in Central or South Bays, where longfin smelt can be abundant. As with Delta smelt, general zooplankton monitoring extended into Central Bay would be adequate for tracking changes in food abundance generally, but zooplankton samples taken in conjunction with the fish sampling provide a more immediate picture of the prey field where the fish are, and are essential if fish diets are to be examined through gut content analysis.

The export facilities also must be considered in tracking environmental change relevant to longfin smelt. Adult mortalities as the facilities should be determined from salvage related to mean catch per trawl in previous November-December fall midwater trawl survey. Mortalities in young life stages should also be tracked with interpretations similar to Delta smelt. Similarly, data from Old and Middle River flows will be relevant for longfin smelt as they are for Delta smelt.

Sacramento Splittail

The Sacramento splittail *(Pogonichthys macrolepidotus)* is a native cyprinid fish with a range that centers on the San Francisco Bay-Delta. Estuary. Accoring to Moyle et al (2004) splittail live 7-9 years, tolerate a wide range of environmental conditions, and have high fecundity. Typically, adults migrate upstream in January and February and spawn on seasonally inundated floodplains in March and April. In May the juveniles migrate back downstream to shallow, brackish water rearing grounds, where they feed on detritus and invertebrates for 1-2 years before migrating back upstream to spawn. Splittail are a state Species of Special Concern and were delisted as a threatened species by the U. S. Fish and Wildlife Service in 2003.

Long-term sampling programs in the estuary indicate that the splittail populations are maintained by strong year classes that result from successful spawning in wet years, although some spawning occurs in all years (Moyle et al 2006). Managing floodplains to promote frequent successful spawning is needed to keep them abundant.

Table 7. Important environmental attributes in a unified monitoring, assessment and reporting for lonfin smelt.

Purpose	ASSESSMENT INDICATORS	EVALUATION METRICS	MONITORING Measurments	FEASIBILITY
Populations	population dynamics	Abundance in Suisun Marsh	Number and size	1
	population dynamics	Monthly salvage densities at SWP and CVP.	Daily salvage densities at CVP and SWP	Type 1

Health	Fish health	1.Median loads of seleniuim in fish 2.Incidence of intersex, deformities presence in all adults sampled. 3.Incidence of infestation in all fish sampled	1.Se, Hg loads in tissues of adults 2. Ovotestis presence 3. external parasite infestation	Type 2
Adequate habitat	Frequency of Inundation in critical floodplain habitat	Total number of days of inundation between February 1 and June 30 each year. Whether flows are adequate to inundate floodplains for at least 45 days in the year. Whether this occurs once per 5 years?	Days inundation of Yolo and/ or Sutter Bypasses	Type 1

Population trends

Population abundance, the first order measure of status for most species, is very difficult to determine for Sacramento splittail. The traditional sampling programs that provide the most consistent catch records are the salvage facilities and the fall midwater trawl. The fall midwater trawl captures few splittail because of the pelagic bias of the gear. Other sampling programs catch too few splittail to permit comparisons or estimates of the total population. Therefore a monitoring program that tracks population abundance or derives an index of abundance over the entire range of this species seems neither feasible nor necessary.

In the past some authors have attempted to track population dynamics from take at the salvage facilities. Sampling there is geographically limited, the area sampled changes with pumping rate and the number of fish salvaged is affected by the abundance of the population and other unresolved factors. As a result salvage values, although readily available, are extremely difficult to interpret. Perhaps the most effective sampling program for Sacramento splittail is the geographically limited Suisun Marsh sampling. The delta and Suisun Marsh are the apparent center of abundance for Sacramento splittail, so consistent monitoring at one location over time is adequate to track population dynamics and has provided a baseline of knowledge about the species (Moyle et al, 2004). Historically, dynamics of the population have rebounded spectacularly from very low levels following extended droughts. However, concern has been expressed that these rebounds have become less through time, raising concerns that the population's resilience may be impaired. These observations should be considered in assessments of future data. If, for example, the rebounds in years when massive spawning is expected show no time trend, and those rebounds occur frequently enough to ensure a successful year class within their usual life span, the species' resilience is assured.

Similarly, juveniles characteristically have poor survival rates, but concern has been expressed that sudden increases in exports near July 1 put young splittail at risk which are dispersing from the no longer inundated floodplains where they were spawned. If survival from month-to-month, perhaps determined from Suisun Marsh population data, are consistent across years, or at least show no trend with pumping rates or across years, then water project operations are probably not exacerbating the usual low survival of young fish.

What. Population dynamics estimated from populations in Suisun Marsh.
Why. Estimate can test resilience of population: is the population self-sustaining?
Target. No formal target. Metric of rebounds in high flow years.
How. Sustain monitoring in Suisun marsh.

Healthy populations.
Because they are relatively long-lived splittail have the capacity to accumulate toxins and parasites. These propensities may be accentuated by feeding, spawning, and rearing on lands used for agriculture or in waters receiving high levels of urban and agricultural contaminants. Sampling in Suisun marsh has found that larger splittial are frequently carrying external parasites; sometimes a sign of contaminant stress in other species. Only a few studies of metal, contaminant load or intersex features have been performed on Splittail, but the technology is straightforward. For example, unpublished data show that Se concentrations are elevated in 2 year old and older splittail that feed in Suisun Marsh, apparently because their diet switches to bivalves at that time in that selenium-contaminated habitat. Tissue concentrations are sufficiently high to raise questions about effects on reproduction (and deformed individuals have been found in Suisun Marsh). It has been argued that the high fecundity of splittail might compensate for exposure to toxins causing reproductive damage. But if resilience is impaired this could either be one cause or it could be a secondary stress factor in years of low abundance. Otherwise effects of chemical are unknown. Useful metrics to systematically monitor in the Suisun marsh population would thus include Se concentrations in tissues, as well as incidence of intersex, deformities and parasite infestation.

What. Metrics of contaminant exposure and effects.
Why. Functional ecology suggests this species might be especially vulnerable to contaminants.
Target. Below threshold for reproductive toxicity of selenium in fish. Small proportion of markers of stress (not a formal target).
How. Build off Suisun marsh and older individuals captured at the export facilities.

Adequate Habitat.
Through all life stages, splittail are tolerant of a wide range of environmental conditions so for growth, feeding and living space they are unlikely to be limited by habitat. Moyle

et al (2004) did emphasize that it is important to provide safe migration corridors between spawning and rearing grounds as well as abundant high-quality brackish water rearing habitat. Most important, however, their successful reproduction has been tied to inundation of floodplain habitats and it is that habitat that seems to be key to their abundance and survival. Because they can live up to ten years, successful reproduction is not required every year, but must occur at least once within an average generational time. Moyle et al (2004) cited the importance of examining how the timing, magnitude, and duration of high flows contribute to the generation of strong year classes. The number of days that Yolo and/or Sutter bypasses (or some other higher floodplain of known value to splittail reproduction) are inundated each year is an example of a metric that could allow tracking the availability of this critical aspect of splittail habitat. Longer term monitoring of the area of such habitat would be important, but methods are not developed.

What. High floodplain habitat critical to splittail reproduction.
Why. Although highly fecund and resilient to year class failure, occasional highly successful periods of reproduction are necessary for splittail and those require sufficient access to floodplain habitat.
Target. No formal target.
How. Monitor length of time in each year that higher floodplain habitats are inundated. Longer term monitoring of the area of such habitat would be important, but methods are not developed.

Sturgeon

According to Macenroe and Cech (1985) white sturgeon, *Acipenser transmontanus* is a chondrostean, an ancient group fish that evolved at least 200 million years ago.The Bay-Delta's native white sturgeon are found along the Pacific coast of North America from British Columbia to California. They are anadromous, migrating up the larger rivers along the coast to spawn. It is believed that they reach sexual maturity between fifteen and twenty years of age, and may spawn every two to ten years thereafter. In the fall white sturgeon enter the estuary from the sea and slowly migrate upstream over the next several months. Spawning occurs during the winter months (February-March). Sturgeon juveniles remain in fresh water from several months to several years, depending on the species (Doroshov 1985). The green sturgeon, *Acipenser medirostris*, is a similarly long-lived native to the San Francisco Bay. Sub-adult and adult fish are oceanic and range from Alaska to Mexico. They enter the estuary during the spring and remain through autumn (Kelly et al, 2007). Green sturgeon are more rare than white sturgeon. Little is known about green sturgeon distribution within the estuary or what, if any, physical parameters influence their movements. Green sturgeon are listed under the Endangered Species Act, and white sturgeon populations were declining when the data were last reported in the 1990's.

Table 8. Important environmental attributes in a unified monitoring, assessment and reporting for white and green sturgeon.

Purpose	ASSESSMENT	EVALUATION	MONITORING	Feasibility
	INDICATORS	METRICS	Measurements	

Population abundance	White and green sturgeon population abundance	a.Number of spawners in breeding holes. b.Total numbers calculated from % reproductive (Green)	a. Continue mark-recapture. b. DIDSON camera survey in habitats >5 m located above Hamilton City for green and Colusa to Hamilton city for White (Feb-Jun)	1 3
Abundance	What proportion are reproducing	Percentage of adults captured in bay or ocean with reproductive hormones	Count fish in Bay: Blood samples from Trammel and fyke netting – white sturgeon side catch samples from ocean fishery, salvage or removed from CCF Feasibility for capture 1, for blood 3	1
Abundance	Total number of white sturgeon	a.Mark recapture in Bay . b.Percent reproducing. c. total population from Bay reproducers and counts of spawners.		
Healthy population	Chemical contamination. Se and Hg	Trends in selenium exposure; changes in Se sources; trends Se & Hg in sturgeon tissues.	Monthly clam samples from Suisun Bay analyzed for Se and stable isotopes of C & N. Model Se in sturgeon. Every 5 years, sturgeon liver and muscle.	1.
	Endocrine disruption	Mix of female and male reproductive hormones in individual adults	Blood samples from Trammel and fyke netting, white sturgeon side catch samples from ocean fishery, salvage at screens or removal from CCF Feasibility for capture 1, for blood 3 Relevance 1	3

Survival of young	Annual index of yearlings from all sampling	Number of young in all sampling	Green sturgeon yearling catch in each sampling/salvage program	1 (great uncertainty)

Because of their broad dietary and environmental requirements sturgeon probably require less subsidiary monitoring than do some other species. For example, high temperatures and low dissolved oxygen could preclude their use of some areas of the estuary but are unlikely to affect survival or growth under present condition in any but a small portions of their ranges. Kelly et al (2007) observed no detectable influence of environmental conditions on movements of green sturgeon.

Abundance

Because of their small population size, broad oceanic range, and limited fishery, traditional mark-recapture studies to estimate green sturgeon population abundance are impossible. However, green sturgeon are limited in their distribution during spawning, with the entire species using only three rivers to spawn in and in limited areas of those rivers. Thus, actual counts are possible of the entire spawning population of green sturgeon in the deep holes in which they breed. Comparable sampling in the Sacramento, Klamath and Rogue rivers would be necessary. Because an unknown (and probably variable) fraction of the population spawns in any year, it is important to accompany census information with hormonal characteristics of a representative fraction of the population. Such data are obtainable from Bay and Ocean catches. From such data calculation of the size of the total adult population would be possible. Monitoring survival of young green sturgeon could also be added to UMARP by counting the proportion of yearlings in sampling programs and salvage.

White sturgeon are more broadly distributed in their spawning, but still spawn in deep holes in main rivers where they can be censused with a DIDSON camera. Fortunately, the adult population spawning in the Sacramento River is closely associated with San Francisco Bay so that extrapolation from the number of spawners and the hormonal characteristics of the bay population allow a useful approximation of the total number of white sturgeon using the estuary. Augmented by the traditional tagging program that has been run by CaDFG for many years, a reasonable population estimate is possible.

Although it is quite feasible to obtain the data described above no systematic monitoring, assessment and reporting effort is yet underway.

What. Population abundance
Why. Population trends are essential for species of concern.
Target. Green sturgeon: de-list
How. Count spawners in deep holes in the upstream rivers. Determine percent reproductive from hormonal analysis of fish caught in ocean and/or Bay. Calculate total.

Chemical contamination

Chapman et al (1986) emphasized that the low reproductive potential of white sturgeon in San Francisco Bay should be considered in fishery management of the species. Thus populations of sturgeon might be especially susceptible to contaminants that cause reproductive damage. Selenium and mercury concentrations in sturgeon are known to be at levels that could begin to threaten reproduction. Selenium contamination is of particular concern. High selenium concentrations are well documented in white sturgeon from San Francisco Bay (Suisun Bay in particular). Sources of contamination include local refineries and the large reservoir of selenium-contaminated soils in the western San Joaquin Valley. Sturgeon are exposed to higher selenium concentrations than other species because their prey include animals that strongly bioaccumulate Se (bivalves) and that Se is readily passed up the food web. Because there is a relatively straightforward relationship between prey concentrations and predator concentrations (Luoma and Presser 2009), monitoring prey (bivalves) would be effective in evaluating trends in Se exposure of sturgeon (Stewart et al, in prep; Presser and Luoma, 2010). A relatively strong body of evidence links Se exposure to concentrations in tissues at which reproductive effects on fish in general and sturgeon in particular. Thus monitoring exposures would allow relatively robust conclusions about risks to reproduction.

Mercury is also a reproductive poison that occurs in high concentrations in sturgeon in the Bay-Delta. Periodic mercury of analyses of sturgeon tissues could be combined with analyses of stable isotopes of C and N allow to link mercury in tissues to sturgeon had been feeding prior to their capture (Stewart et al, 2004; in prep.). Like selenium, a relatively robust body of evidence is available to link mercury concentrations in fish to risks to reproductive damage (Wiener and Suchanek, 2008).

Fifteen years of data showing selenium trends in bivalves from Suisun Bay exist; as does a baseline of data on selenium and mercury concentrations in white sturgeon. Continuation of the seleniuim bivalve monitoring accompanied by analyses of sturgeon tissues for stable isotopes, selenium and mercury at five year intervals would allow continuous tracking of these important issues into the future. Stable isotopes of carbon, nitrogen and sulfur can be easily analyzed in animal tissues and can identify where a fish was feeding prior to collection. Comparisons of fish feeding in Suisun Bay to fish that were feeding in the oceans would allow robust tracking of contaminant conditions in the former as water management changes.

Monitoring selenium and mercury in the Bay-Delta food web is especially important in addressing UMARP's grand challenges. The massive reservoir of selenium that exists in the western San Joaquin Valley and the lack of a clearly sustainable plan to deal with irrigation drainage from that region suggests exposure of sturgeon during their residence in San Francisco Bay could increase in the future, depending upon water management decisions that affect inflows from the San Joaquin River to the Bay (see Healey et al, 2009). Exposures to mercury, similarly, could increase if restoration of wetlands accelerates methmercury production in the system (building from the wide scale contamination left behind by hydraulic gold mining and mercury mining). Although themselves a precious species, sturgeon are also a broader "canary in the gold mine" indicator for other species at the top of the food web that might be vulnerable to bioaccumulative toxins like mercury and selenium.

Future indicator. Chemicals that cause endocrine disruption could also threaten reproduction in sturgeon. Although less is known about actual exposures to such chemicals in time and space, periodically monitoring reproductive hormones in the blood of sturgeon caught in various programs would be a feasible way to track changes in this potential stressor.

What. Monitor selenium and mercury and model effects on reproduction.
Why. The low reproductive potential of sturgeon and the existing elevated concentrations of these contaminants in their tissues suggest chemicals that damage reproduction constitute a risk to the population.
Target. Concentrations below the thresholds that cause reproductive damage.
How. Monitor selenium in bivalves from Suisun Bay monthly for short-term feedback on trends. Monitor sturgeon tissues for stable isotopes, selenium and mercury and sturgeon blood for reproductive hormones every five years to assess longer-term changes.

Fish with a commercial constituency: Large mouth bass

The largemouth bass *(Micropterous salmoides* L.) is an important fish species for anglers throughout the United States. It is an invasive species in the San Francisco Delta but with a large and growing constituency of anglers. It is thought that populations of LMB are growing, perhaps because they seem to benefit from the expansion of invasive submerged aquatic vegetation. Because they are voracious predators, LMB may also negatively influence populations of native fishes. Monitoring, assessment and reporting on large mouth bass is therefore important to the fishery of the species itself and important to understanding the role its predation in the well-being of native species. Unfortunately, there is very little systematic data collection on LMB underway so most of the suggestions would require new investments in monitoring.

Table 9. Important environmental attributes in a unified monitoring, assessment and reporting for large mouth bass.

Purpose	Indicators	Metric	Monitoring Variables	Feasibility
Recruitment	Juvenile Recruitment	Ratio of YOY: biomass of adults or reproductive fish.	Abundance (in July/August) estimates for YOY and adults (FL > 200mm).	**2**

	Population Trends	a. abundance estimates for total population across years; b. Regional abundance estimates juvenile and for piscivorous pop'n	**a.** Number of LMB in salvage; b.total CPUE from efishing efforts across years; c. E-fishing densities of fish > 125mm FL (piscivorous) and juveniles (<125mm) for each major Delta region	a. 1. Salvage b. 2. Build on DFG e-fish datasets (
	Population trend	Trends across years in the LMB caught in fishing tournaments;;	Catch-per-unit-effort in tournaments;	1
	Community composition (centrachids)	Proportion of centrachids that are LMB species.	Identify fish species (and subspecies?) in electrofishing surveys	2.
Habitat: biotic & physical	SAV distribution	Change in total area covered by SAV across years. Use delta-wide and regional coverage and electrofishing densities to estimate total population.	Overall coverage (% cover, total area covered), and coverage within each Delta region.	1: hyperspectral imagery. 4**:** Use of LandSat images.
	Temperature	Regional & seasonal variation in in nearshore temperature.	A) Adults: Duration where temps are 27-30 degC. B) Juveniles: Duration where temps are 30-32 degC. C) # days below 10degC	**3.**

	Turbidity	Regional & seasonal variation in temp. in nearshore areas. Compare average temps and temp range between SAV & non-SAV nearshore areas.	Days/seasons/regions where turbidity >10NTU.	**Type 3.** No effort yet to monitor turbidity across nearshore habitat types, but the technology exists. May also be possible to extract turbidity from remote sensing data.
Impact of LMB as predators of native fish	Diet composition	Fish species present in stomach contents.	A) Genetic tools to determine presence or absence of native fishes in stomach contents. B) Compare diet composition between Delta regions and habitat types.	3**.**
	Response to restoration efforts for native fishes	Abundance in newly created tidal wetlands	Use of seasonally inundated areas; abundance trends in restoration areas	**Type 4.**
Chemical contamination	Mercury contamination	Mercury contamination of LMB	Mercury concentrations in muscle and liver of 20 LMB of different sizes every year, from the Delta. Stable isotopes of C & N.	

Population Status and Trends

Future feasible indicators. Salvage and *ad hoc* electrofishing surveys indicate LMB populations are increasing in abudance. Thus some historic data exists, but sampling has been irregular since the early 80s. Because systematic collection of such data has not been instituted there is substantial uncertainty about population size and even trends. Systematically evaluating salvage data might provide very coarse estimates of trends, although the uncertainties in that data are well known. Similarly number and size of LMB, per unit effort, caught in line fishing tournaments might also be a coarse indicator of large changes in populations from year-to-year. But a robust estimate of populations and trends would require instituting a systematic monitoring program with effective methods; i.e. electrofishing is the preferred methodology to sample the widest variety of habitat types, and probably the only way to sample areas with heavy SAV. This could entail a concentrated sampling effort and development of methods to extrapolate abundance from e-fishing densities. Random sampling within each major Delta region (Central, North, East, South, and West, as per Brown & Michniuk 2007) could provide data on both total populations and regional trends. Sampling sites should be selected in a hierarchically randomized manner, such that each region and habitats within each region are represented. Electro-fishing datasets from early 1980s and early 2000s used this general approach, but these sampling efforts have been discontinued. A UCDavis study in 2008-2010 sampled across Delta regions, but revisited the same locations with each sampling effort.

The effort required would entail approximately 10 sites within each Delta region (~50 sites total), and 3 weeks in the field for each sampling session. To evaluate the full life cycle, sampling should occur three times per ear. Spring sampling in about April would estimate abundance of spawners, and number of juveniles recruiting through the winter. August sampling would estimate the Young-of-the- Year (YOY) abundance derived from the spawning occurring the previous April/May. The ratio of the young-of-the year (YOY) produced (<200 mm) to the estimated biomass of the reproductive population is a metric that can be used to evaluate how the LMB population is changing. November/December sampling would provide an estimate of populations during the time when native fishes are migrating (most vulnerable to predation) in the system (e.g. in Delta smelt migration corridors) and would develop abundance estimates at the onset of winter in order to evaluate overwinter survival.

LMB typically become piscivorous at about 125mm FL. If size as well as numbers were recorded it would be feasible to estimate the abundance of important predators in the system. It is also important to evaluate if this ratio is varying regionally.

An additional consideration would be the relative abundance of the two sub-species that are present. Both Northern (*Micropterus salmoides salmoides)* and Florida (*M.s. floridanus)* subspecies have been introduced. Uncertainties exist with regard to the relative fitness and growth of the two subspecies. Conventional wisdom is that Florida largemouth have faster growth rates, increased longevity, and are more voracious predators than Northern bass. However, other work has shown that Florida largemouth have a more restricted range of temperature tolerance than northern largemouth bass (Phillip, 1992). The relative performance of the two strains in the Delta is not well known, nor is it known if there is a difference between subspecies with respect to their impact on native species. It is also possible that the Florida strain continues to be "informally" introduced.

What. Estimate abundance of LMB.
Why. Representative of an invasive predator that presents a risk to native species abundances. Has a strong commercial consitituency, so trends are important for their own sake.
How. Probably electrofishing, but exact methodologies and metrics need development. ,

Habitat: biotic and physical

The association of large mouth bass with SAV is well know in the Bay-Delta and elsewhere. Thus understanding the area of habitat occupied by SAV would provide an indicator of habitat. The Center for Spatial Technology and Remote Sensing (CSTARS) is working on LandSat data to develop an historic database of SAV distribution. If successful, this could also be used to estimate coverage in future years. CSTARS also has 5 years of data 2004-2008 and models for analyzing spectral signature that have been validated. If hyperspectral imagery is cost prohibitive, it may be reasonable to conduct fly-overs every 2-3 years rather than every year to reduce cost. Some regional breakdown of data should also be considered. For example, it would be valuable to know whether SAV is expanding into the North Delta. Although LMB population sizes remain relatively low there, an increase in SAV is likely to encourage an increase in that region.

Temperature is also an indicator of LMB habitat. Juvenile bass prefer temperatures that are slightly warmer than adults (Moyle, 2002). Apparently, growth of LMB occurs over a range of 10-35 degC. , but optimal temps for adults are around 27^{o} C. The number of days where temperatures are < 10^{o} C may be useful metric to estimate the extent to which winter temperatures limit bass production. More complicated metrics could be devised that take advantage of this knowledge. No efforts yet exist to measure temperature in nearshore areas with different habitat types, but technology exists.

Turbidity is another indicator of habitat. Shoup & Wahl (2009) found that LMB reduced their selectivity for fish (bluegill) and increased their selectivity for crayfish at 10NTU. More work needs to be done, but reporting a turbidity metric in the LMB story may be a good starting point for identifying where LMB may start having a harder time locating fish prey, providing a target for monitoring turbidity in different habitat zones.

What. Area of SAV, temperature, turbidity from selected locations.
Why. Indicator of suitability of habitat for LMB.

How. Surveillance network for latter and satellite imagery for former. Data or at least methodologies exist.

Diet: Impact of LMB as predators of native fishes.

Future indicator: Moderate feasibility. Previous studies demonstrate high degree of variability in LMB diet (Schindler, et al. 1997). Of interest in the Delta is how different the diet is in areas where the SAV-associated food web is not as prevalent and/or in refuges for native fishes (e.g. Liberty island?). Monitoring gut content is the traditional way to address questions like this. But genetic markers for important prey species like Delta smelt are established and are already being used to assess Mississippi silverside predation on larval smelt. The same technology could be applied to largemouth bass diet samples. Variability in diet across regions and habitats could also be informative. Determination of changes in diet (or lack of change) would be particularly relevant for samples collected from bass residing in areas close to known presence of Delta smelt.

Chemical contamination

Because large mouth bass are a top predator they could be an excellent indicator of mercury contamination in the Delta. In other environments they are one of the organisms with the highest mercury concentrations (Stewart et al, 2009). This issue is important for two reasons: a) there is a question about mercury mobilization from restoration projects in the Delta because of the sedimentary contamination of mercury through much of the region. b) Large mouth bass are consumed by humans, presumably, because of the substantial sport and subsistence fishery in the region. Mercury is a serious human toxin if contaminated fish are eaten with regularity. Inclusion of C and N stable isotopes could help identify where the fish are feeding.